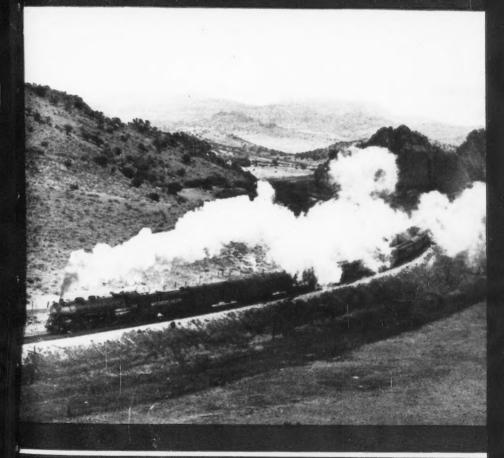
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MAY, 1948 VOLUME_4 NUMBER 5

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Entered as second class matter October 31, 1946, at the Post Office at Houston, Texas, under the act of March 3, 1879.

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devoted entirely to CORROSION Research and Control

PUBLISHED MONTHLY AS ITS OFFICIAL JOURNAL, BY THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS, INC., AT HOUSTON, TEXAS, U. S. A., TO PROVIDE A PERMANENT RECORD OF PROGRESS IN THE CONTROL OF CORROSION AS DESCRIBED IN PAPERS PREPARED FOR THE ASSOCIATION AND FROM OTHER SOURCES.



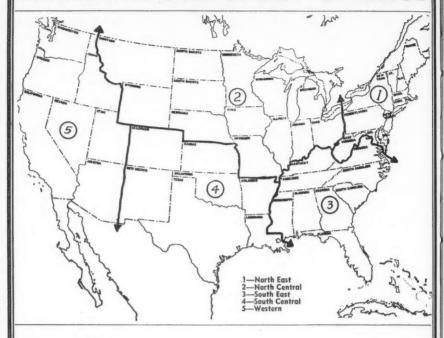
CONTENTS

Effects of Hydrogen Generated by Corrosion of Steel By M. H. Bartz and C. E. Rawlins	7
Effect of Atmospheric Corrosion on Maintenance and Economics of Overhead Line Hardware and Guy Strand—Part 2 By C. J. Couy	7
Organic Coatings for Corrosion Protection—A General Discussion By G. W. Seagren	9
Salt Water Corrosion of Ships By R. A. Pomfret and L. M. Mosher	7
A Message From Your Officers	x
Conference and Exhibition Resume	1
NACE Awards 8-	9
NACE News	0
Abstracts	7
Index to Advertisers	2

THIS MONTH'S COVER

• Southern Pacific's westbound Sunset Limited in the pass at Paisano, near Alpine, Texas, in the Davis Mountains, highest point (5074 feet above sea level) on the New Orleans-Los Angeles route. Rail carriers in this country have long recognized that corrosion control contributes toward higher handling capacities and maintaining faster schedules, with minimum delays. Photograph courtesy Southern Pacific (Texas-Louisiana Lines) Houston, Texas.

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A Message from Your Officers

This Month's Contributor

H. H. ANDERSON, Vice President of NACE



As corrosion engineers we have an exceptional opportunity to serve industry. With the ravages of corrosion running each year into hundreds of millions of dollars, the profits to be gained from its control are enormous.

Our Association gives us a splendid forum in which, through the pooling of our collective ideas and experiences, each of us can attain the stature needed to meet corrosion's challenge on our own job.

I remarked at our last annual dinner that as a group, "We range from researchers with heads in a cloud, to field men with heads in a trench." In fact, some of us are groping in that trench—confused in technology, terminology and economics.

Research is the Golden Calf of American business, and there is need for a lot of it in OUR work. We must retain a scientific attitude so that we can learn more about the fundamentals of corrosion and its prevention.

But we call ourselves corrosion "engineers" (not "researchers") which means we should apply our art in a practical manner. It means that we should strive for effective results from proved techniques based on sound economics. It means that in corrosion control we must exercise good business judgement parallel with our exercise of good technical judgement.

To make my point—As technologists we know how to coat a buried structure effectively and how to protect it cathodically. But given the job of protecting an old one, perhaps as engineers we are in doubt as to which technique will be the most effective and which should prove most economical in the long run.

It takes years for an individual through his own experience to solve such an engineering problem, but the pooling of our collective experience should soon accumulate the case data needed for solving most current problems.

If the NACE is to be in fact an "engineering association" and not a "technical society." I suggest that as engineers we should direct more attention in its program to the economic aspects of corrosion control.

THE NATIONAL ASSOCIATION OF CORROSION FUGINFERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

- (a) to promote scientific research in determining the causes of corrosion and methods of its control with respect to theory and practice.
- (b) to provide a means of exchange of knowledge and ideas among those individuals actively engaged in the control of corrosion.
 - (c) to promote methods of control of corrosion.
- (d) to promote standardization of terminology, methods, equipment and design in the development of methods of corrosion control.
- (e) to foster cooperation between individual owners of metallic structures in the solution of their joint corrosion problems.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers are nominated by (1) the Board of Directors, or (2) a quorum of at least 25 members, and elected by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 905 Southern Standard Building, 711 Main Street, Houston 2, Texas.



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Effects of Hydrogen Generated By Corrosion of Steel*

By M. H. Bartz* and C. E. Rawlins*

ALTHOUGH metal loss is usually regarded as the most harmful effect of corrosion, there are numerous examples of corrosion fatally damaging petroleum processing equipment long before the loss of metal is of any significance. Hydrogen released during corrosion is responsible for this damage, which

manifests itself as embrittlement of hardened steel parts and blistering of unhardened parts.^{1,6}

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> Embrittling and blistering have been encountered in equipment handling sour crudes, sour crude fractions, sour natural gases and gasolines, as well as in equipment handling hydrocarbons

and hydrofluoric acid.^{3,6} Blisters vary in size from less than one-eighth inch in diameter, to those as large as twelve inches by twenty-four inches. similarly, the number of blisters may vary from one piece of equipment to another, and may vary within different areas in the same structure.

A large number of small blisters



Figure 1—Small blisters which developed on outside surface of a sour crude storage tank.

^{*}A paper presented at the Annual Meeting of NACE, in St. Louis, Mo., April 5-8, 1948.

^{*} Engineering Department, Phillips Petroleum Co., Bartlesville, Okla.

are shown in the wall of a sour crude storage tank in Figure 1. Figure 2 shows a single large blister that developed in the wall of a 12,000-barrel blimp used to store natural gasoline. Other plates in this blimp contained both large and small blisters.

A cross section of a blistered plate is shown in Figure 3. Small portions of the plate had bulged outward, as though from high internal hydrostatic pressures. Cracks were found along the edges of the blisters, nearly radial to the bulged plate surface.

In a recent survey, fourteen natural gasoline absorption plants were examined for blistered equipment. Ten plants processed sour gas with hydrogen sulfide content of 10 to 287 grains of hydrogen sulfide (H₂S) per 100 cubic feet of gas. Four plants processed sweet gas. Blisters were



Figure 2—Large blister on outside surface of a blimp storing sour natural gasoline at 65 psi.

found in the equipment of five of the plants handling sour gas. No blisters were found in the plants handling sweet gas. This strong evidence indicates hydrogen sulfide as being the corrodent responsible for blister formation.

In these natural gasoline plants, the vessels in which blisters were most often found were the make tanks, low-stage accumulators, highstage accumulators, water legs just upstream from make tanks, and spheres, blimps and cylindrical vessels storing raw natural gasoline.

Crude Refineries

In crude refineries, blisters have been found principally in accumulators and feed tanks containing the lighter hydrocarbons from which hydrogen sulfide has not been removed. In one blistered vessel, the stream contained propanes and lighter with only four percent by volume of butanes and heavier; in another, less than 15 percent of the stream was pentanes and heavier. Depending upon operations, the total sulfur in these two streams, respectively, ranged from 0.646 to 1.23 weight percent and from 0.077 to 0.268 weight percent. The blisters in these vessels and in the natural gasoline vessels were much worse in the bottom than in the sides and top.

Blisters have been found in hydrofluoric acid alkylation units in the contactors, the acid settling tanks, the azeo feed tanks, azeo accumulators, vent gas neutralizers, acid oil legs and in anhydrous acid storage tanks. 1.4

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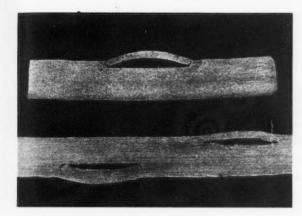


Figure 3—Cross sections of blistered plates, Note that two blisters had cracks progressing from their edges toward plate surface.

Only one case of blistered line pipe has been experienced. Unfortunately little history of that sample is available. The blisters were noticed in a length of reconditioned pipe that had failed from a long longitudinal split (Figure 4). It was not possible to ascertain definitely the previous service of the pipe, but there were indications that it had been in pipeline service, and a light sulfide scale on the interior service suggested that it had been used for sour materials. This case was of particular in-

terest because blisters have not been found in process piping that serves blistered vessels.

Numerous blisters have been drilled into, and many released gas that burned with a blue flame. On several occasions, this gas ignited from a spark caused by an electric drill, and occasionally rather violent explosions occurred.

A sample of gas was tapped from one blister which developed in the wall of a sphere operating at 135 psi in sour natural gasoline service.

Figure 4—Blisters on inside wall of lap welded pipe. Pipe failed from a longitudinal split. No blisters were visible on outside surface.

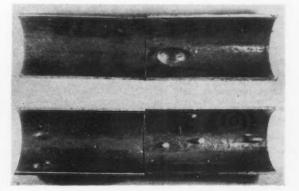




Figure 5—Blisters on underside of a horizontal sour natural gasoline storage tank. Tank fractured along knuckle of one head.

The pressure of the gas within the blister was 140 psi. The composition of the gas was found to be:

Hydrogen ...99.5 \pm 0.5 volume percent Water vapor Trace Carbon dioxide 0.05 ± 0.02 volume percent Air 0.3 ± 0.1 volume percent Carbon monoxide ... 0.05 ± 0.02 volume percent

The sample was first analyzed for hydrogen by conventional analytical methods. The composition of the gas, other than hydrogen, and the quantity of the other components were determined by mass spectometric methods. No methane, hydrogen sulfide or ammonia was found

in the sample. The threshold sensitivity of the mass spectrometer was 0.03 percent of either methane or hydrogen sulfide and 0.1 percent ammonia. There is some possibility that the method of obtaining the sample allowed some atmospheric air to contaminate the sample.

Five blisters which developed in a vessel in refinery service were tapped to establish the pressure of the entrapped gas. Pressures of 1000, 1700, 2500 and 2700 psi were recorded. These blisters, ranging in size from three inches by four inches, to four inches by six inches, were about one-half inch beneath the surface of a one and five-eighths inch thick plate. The maximum pressure to which the vessel had been exposed was 270 psi during service and 405 psi when the vessel was tested before installation.

Blisters in Pressure Vessels

The seriousness of hydrogen blisters in pressure vessels was forcibly called to our attention several years ago with the failure of a sour natural

Figure 6—Blisters on inside surface of failed vessel. Note cracks along edges of blisters. Occasionally only pits remain after corrodent enters these cracks and attacks raised portion of blister from all sides.



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Figure 7—Cross section of blistered plate from failed vessel. Failure occurred along a line of cracks which developed from a series of blisters that cracked toward the plate surface.

gasoline storage tank. The head of the cylindrical vessel blew off after it had been removed from service and was filled with gas at 30 psi. This pressure was appreciably lower than pressures often applied to identical vessels. Failure occurred at the knuckle of one head, and fortunately caused no fire or damage to equipment other than the failed vessel. The vessel was found to be badly blistered. The blisters along the knuckle of the failed head had torn open to the inside plate surface forming a discontinuous chain of cracks along the line of failure. In this vessel, as noted in many other vessels, some of the plates had blistered while adjoining plates appeared to be blister-free. Some of the blisters found on the outside of one of the plates are shown in Figure 5. Most of the blisters are small, and, although not clearly shown in the photograph, were oblong, with the major axis in the rolling direction of the plate.

When the inside of the plate was examined (Figure 6), many tiny blisters were found that had cracked along their edges. These cracks are shown in Figures 6 and 7.

A cross section of the plate showed blisters at different levels beneath the surface (Figure ?). The largest blister shown in Figure ? had bulged toward the outside of the plate as would be expected from its location within the plate. Cracks at the edges of this blister migrated

toward the surface nearly perpendicular to the plane of original progression of this blister. In many other blisters, these cracks connected the blisters with the surface of the plate. It was a series of such cracks, formed from blisters near the inside surface, that served to weaken the most highly stressed portion of this vessel and along which the fracture progressed.

Unexplained Behavior

Another severe example of blistering was found in the bottom head of a 12,000-barrel blimp which had been in raw natural gasoline service for five years and in de-ethanized natural gasoline service for six years. The working pressure in both services had been near the vessel's designed pressure of 65 psi. Many blisters were found, but only in the bottom hemispherical head. The most severely blistered portion of the vessel could be contained in a band encircling the head between 45 and 70 degrees south latitude. (Considering the exact bottom of the hemispherical head the south pole and the equator as the joint be-

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tween the head and the cylindrical portion of the vessel.) This has been consistently observed in other vessels. As yet, no explanation can be offered for this behavior.

Blisters in this vessel ranged in size from very small to 12 inches by 24 inches. Some of the plates contained many blisters of varying sizes randomly scattered through the plates, other plates were

blistered at one end but free from blisters at the other end, while still other plates appeared to be blisterfree. The condition was comparable to that shown in Figure 8. Since all plates were exposed to nearly identical corrosive conditions, an effort was made to determine any metal-

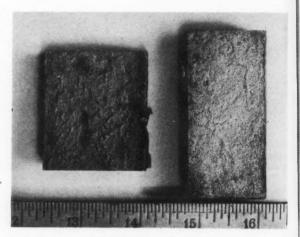


Figure 9—Sample at left from blistered plate; sample at right from a plate thought to be blister-free. Actually, both plates had blistered, as shown by small cracks in both samples.

lurgical causes that may have accounted for the differences in plate performance.

When the scale covering the inside surface of the plates was removed, it was found that all the bottom head plates, including the ones that were thought to be blister-free,

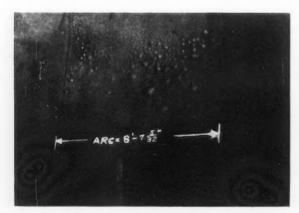


Figure 8—Blistered plate, with adjoining plates blister-free.

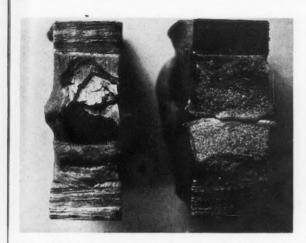


Figure 10-Appearance of fractures of slowly bent, notched samples from blistered plate (left) and blister-free plate (right).

contained short parallel cracks, of the nature shown in Figure 9.

The sample at the left in Figure 9 was taken from a badly blistered plate and contained larger and deeper cracks than the sample shown at the right that was from a plate thought to be blister-free. The cracks were edges of blisters that had torn open to the plate surface. This

showed the original assumption, that some plates had blistered and others had not, to be incorrect. However, there was a difference in the size of blisters and in the depth at which they developed in different plates.

A chemical analysis of a badly blistered plate and a blister-free plate showed little differences in composition. Also the mechanical properties of the plates were very sim-

ilar (Table I).

The differences in breaking strength (breaking load divided by breaking area) were at first thought to be significant, but other tests with blistered steels from other plates and other vessels would not duplicate these differences in breaking strengths. When impact specimens were machined from the plate and broken with the notch parallel

TABLE I Chemical Analysis of Blistered and Blister-free Plates

	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Aluminum
Blistered plate	0.24 0.25	0.58 0.47	0.009	0.028 0.024	0.06 0.09	0.008 0.006

Mechanical Properties

	Yield Strength	Ultimate Strength	Breaking Strength	Elong. in 2 Inch	Reduction of Area %
Blistered Plate:					
Longitudinal	40,500 38,100	58,100 56,200	59,000 52,000	25.5 27.5	63 57
Blister-Free Plate:					
Longitudinal	43,100 39,500	63,200	128,000 98,000	32 34	62 54

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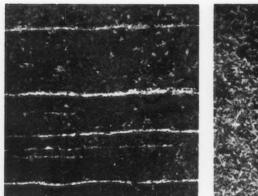
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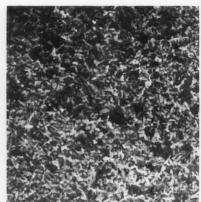


Figure 11—Behavior of blistered steel (left) and blister-free steel (right) when etched with Stead's reagent.

to the surface and perpendicular to the rolling direction, the samples from the badly blistered sheet absorbed 45 foot pounds of energy on breaking, while the samples from the blister-free sheet absorbed only 29 foot pounds. Samples broken with the notches perpendicular to the original plate surface and perpendicular to the rolling direction showed much less difference in impact resistance; the blistered plate absorbed 25 foot pounds and the blister-free plate absorbed 28 foot pounds energy in breaking. This suggested a banded or laminated structure, which was verified by the appearance of fractures of slowly bent notched samples (Figure 10) The plate that was badly blistered broke with a very fibrous fracture; the plate that was blister-free broke with a crystalline fracture.

Micro-examination of the blistered and blister-free plates showed only one difference, and that may be important. Upon etching with Stead's Reagent, the blister-free steel was uniformly etched while the blistered sample etched with white bands. This was taken to indicate that there was a non-uniformity of composition across the plate, and it probably was phosphorus that had segregated into bands. While this was not reflected in the chemical analysis, it may be that, while the total phosphorus of the samples was the same, the mode of distribution differed. Etching characteristics of the two steels are shown in Figure 11.

Additional evidence that blisters may preferentially form in high phosphorus areas is shown in Figure 12. The edge of the large blister shown in the upper left of Figure 12 had progressed along a phosphorus-rich band. The crack progressing downward at an angle to the band was a crack developing toward the plate surface. Many other cracks, seemingly independent of the blister, were found nearby in the same phosphorus-rich band.

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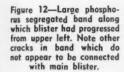
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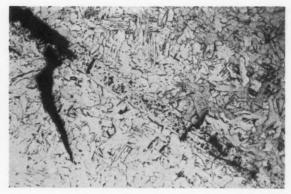
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EFFECTS OF HYDROGEN RELEASED DURING CORROSION





phorus on the formation of blisters, it is interesting to recall that Armbruster7 found no observable correspondence between composition of low alloy steels and order of hydrogen solubility except for an indication of increased solubility with increase of phosphorus content.

Large inclusions or stringers of small inclusions may also serve as nucleating points for blisters. A blister penetrating along a line of disconnected alumina type inclusions occurred in a piece of 24-inch diameter seamless pipe that was used as a small pressure vessel. Figure 13 shows the edge of a blister that formed at a very large slag inclusion in a piece of lap welded pipe.

Large blisters are probably actual laminations in the plate that opened from hydrogen accumulating under high pressure during service. When some of the larger blisters were opened (Figure 14), their inside surfaces were found to be covered with a greyish layer of non-metallic materials. There was little evidence that these surfaces had ever been welded together. Figure 15 shows

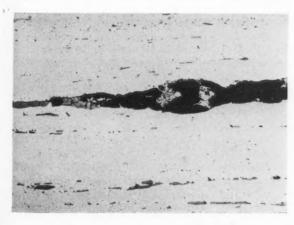


Figure 13-Blister developing along a large slag inclusion. Much of the inclusion remained unattacked within the blister cavity.

a series of blisters developing, all in the same plane. This may suggest a series of unwelded blow holes or a large lamination that had welded together in spots during the plate's rolling operation.

Althoughnot shown in Figure 15, even blisters of this nature are frequently cracked between the lamination and the plate surface, Since the blistered layer of

metal has bulged very little, their location is difficult to determine by visual means alone. The Audigage has been found helpful in locating these internal breaks which are parallel to and beneath the surface of the plate. Magnetic particle inspection will reveal cracks that reach the surface and frequently give an indication of sub-surface cracks which are perpendicular to the plate surface along the edges of blisters.

The exact conditions of the steel that are most ideal for blister formation are not too clear. Without doubt, laminations and other massive discontinuities in the steel will develop into blisters under blister promoting conditions. It is difficult to believe that blisters that occur very frequently in a plate, as those shown in Figure 1, form only along laminations. It is almost certain that the small blisters, one-quarter inch and smaller in diameter, that form predominantly near the corroding surface, are not entirely associated



Figure 14—Appearances of surfaces a blister showing rolling direction. Surfaces were covered with a layer of non-metallics that had resisted welding during rolling operations.

with laminations. Unwelded gas pockets, large inclusions, phosphorus banding and stringers of inclusions may be strongly suspected as other conditions favoring blistering.

Although investigation of the blimp described was more extensive, other investigations have revealed more seriously damaged vessels. One 10 foot by 35 foot vessel, designed for a working pressure of 216 psi, developed many small. blisters and thirteen large blisters ranging in size from 3 inches by 4 inches, to 10 inches by 24 inches. The shell thickness was one inch. The depth of blisters was from 11/32 inch to 17/32 inch beneath the inside surface. Metal loss from corrosion was negligible. The most serious factor in this vessel was that the large blisters had concentrated in a narrow circumferential band of one shell plate. The blisters were cracked at their edges and furnished a series of cracks, almost a straight line, penetrating half the thickness

EFFECTS OF HYDROGEN RELEASED DURING CORROSION

of the shell. The longest crack, at one edge of the 10 inch by 24 inch blister, was at least 18 inches long and one-half inch deep. This crack, for most of its length, had penetrated from the inside of the blister entirely to the inside surface of the plate and, of course, had allowed the gas pressure of the blister to escape. In this vessel, as in many others, the blisters were elongated in the direction of rolling of the plate, and were located in bands or strips parallel to the direction of rolling.

Another vessel, 10 feet by 37 feet, having a shell thickness of 15% inches and a design pressure of 300 psi, had 27 blisters ranging from 2 inches by 2 inches to 14 inches by 18 inches plus a multitude of smaller ones. The blisters were from 0.18 to 0.81 inch below the surface; many had split and allowed the slightly corrosive solution access to fresh metal deep within the plate. Again, only slight metal loss from corrosion was found in this vessel. The minimum wall thickness found was 1.64 inches and the deepest pit was 0.03 inch.

The fact that over 50 blistered pressure vessels have been found in the refineries and natural gasoline plants of Phillips Petroleum Company alone, emphasizes the seriousness of blistering in petroleum processing equipment.

Embrittlement

Blistering is only one of the harmful effects that result when hydrogen is released during corrosion. Embrittlement also has long been associated with hydrogen in steel. The petroleum industry has had ample opportunity to observe hydrogen's contributions to embrittling processing equipment.1,6

Sucker rods, removed from wells with high hydrogen sulfide content, have been found to be glass-brittle. Years ago, operators poured hot oil over brittle rods to "drive out the sulfur" and restore the rods' ductility. Although the operators were not aware of the precise mechanism that caused their rods to lose and regain their ductility, the methods were most practical and effective.

Breakage of 12 percent chromium steel valve springs (Figure 16) in valves handling water saturated with hydrogen sulfide at 40 to 100° F. has been observed in as little as three hours time. Gasoline plants in

West Texas and New Mexico were troubled with extensive breakage of 12 percent chromium steel bourdon tubes and relief valve springs. Bolting has failed in a brittle manner in hydrogen sulfide service. Springs frequently broke in sour crude pumps. In

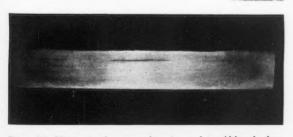


Figure 15—Blisters in the same plane in a plate. Although these bulged very little, a cross section would show cracks developing toward the plate surface.

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equipment handling hydrocarbons and anhydrous hydrofluoric acid, springs ASTM-A-96 class C bolting, hard lock washers, cold rolled SAE 1020 steel bolts and hardened plugs from valves frequently cracked in brittle manner.

Fortunately, most of the embrittled parts have been small and it has been economical to use more costly alloys that are resistant to

the corrosive agents encountered. Bourdon tubes and relief valve spring breakage in hydrogen sulfide service has been eliminated by the use of AISI Type 316 austenitic chromium nickel steels. In other instances, spring breakage in hydrogen sulfide service has been reduced or cured by using Inconel springs or by spraying the steel springs with aluminum. Monel coatings on hardened plugs for valves were found to reduce the type of failures shown in Figure 17. In some cases it has been necessary to use K-Monel bolting to withstand the embrittling action of hydrofluoric acid.

Methods of combating embrittlement, other than by using alloys or coatings that are not corroded by the stream, may be more economical in some situations. The use of low strength, low carbon steels, operating at low stresses may reduce embrittlement at times. Design changes that will not permit the



Figure 16—Twelve percent chrome steel valve springs which failed in a few hours in hydrogen sulfide service.

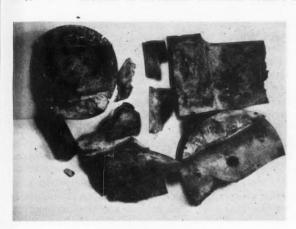
corrodent to contact hardened, high strength, highly stressed steels will offer other advantages.

In all of the above examples, it will be noted that embrittlement was reduced if steel was coated with an alloy, or if an alloy was substituted for steel that would not react with the surrounding corrodent to release hydrogen. Embrittled parts have been observed to regain their ductility some time after being removed from the corroding medium.

Behavior of Hydrogen in Steel

There is little room for reasonable doubt that hydrogen will blister and embrittle steels at low temperatures. Since embrittlement is not limited to the surface of steels and since blisters develop in the center of heavy plates, any mechanism that explains how hydrogen damages steel must explain how hydrogen penetrates steel.

It is quite generally agreed that only atomic hydrogen will enter into



EFFECTS OF HYDROGEN RELEASED DURING CORROSION

Figure 17—Hardened steel plugs for valves which failed in hydrofluric acid service.

and diffuse through the crystal lattice of steel. Molecular hydrogen will not penetrate the metal surface. If two atoms of diffusing hydrogen combine within a metal to form a molecule of hydrogen, that molecule is largely incapable of further migration. Similarly, if diffusing atomic hydrogen reacts (at high temperatures) with carbon, oxygen, nitrogen or sulfur within the steel, the newly formed molecules are incapable of diffusing through the grain.

The damage from hydrogen is associated with hydrogen that has penetrated into the solid metal. Since only atomic hydrogen will enter a metal, the conditions that offer atomic hydrogen to the surface of steel are critical in establishing the amount of damage that may occur.

High temperatures, the presence of moisture or the release of nascent hydrogen by corrosion, pickling or electrolysis are effective methods of furnishing atomic hydrogen to a metal surface.

At low temperatures, the equilibrium established by the reaction

 $H + H \rightleftharpoons H$ is far to the left and very little atomic hydrogen is present, even in an atmosphere of pure hydrogen. Hence, it is possible to store commercial hydrogen in steel containers for long periods of time without losing any

hydrogen and without deteriorating the carbon steel containers. At high temperatures, the above reaction comes to equilibrium with larger amounts of atomic hydrogen in the system. Steel exposed to hot hydrogen may be attacked because more hydrogen atoms are present at the metal surface.

The concentration of hydrogen atoms on the surface of steel may be very great during acid corrosion, pickling or electrolysis. Under certain conditions, metals (steel included) will evolve hydrogen on immersion in an acid. During this reaction there is an exchange of metal and hydrogen ions at or very near the surface of the immersed metal. Some hydrogen atoms will combine with others and bubble off as hydrogen gas, but, many atoms will always be available for diffusion into the metal.

The hydrogen sulfide found in sour crudes and gases dissolves in the small quantities of water fre-

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quently found in producing, refining and gasoline plant operations. A weak acid is thus formed that is capable of attacking the sides of steel containers and releasing hydrogen. Where acids are intentionally used in the process, other equipment is susceptible to the same kind of attack.

Very small quantities of certain "promoters" have been found to greatly increase the amount of hydrogen that will penetrate steel during acid pickling. 9,10 Sulfur, arsenic, selenium, telurium, antimony and phosphorus are extremely powerful in promoting hydrogen absorption. Small quantities of hydrogen sulfide bubbled through pickling solutions have been found to greatly increase the total embrittlement and possibly the rate of embrittlement of steel wires. 11

In view of the large quantities of hydrogen sulfide handled in petroleum processing equipment, the specialized effects of sulfur compounds are of great importance. Hydrogen sulfide not only liberates more hydrogen by increasing the total corrosion, but has the added powerful effect of promoting the entry of that hydrogen into the metal being corroded.

After steel has absorbed hydrogen, it will be affected in a manner that is dependent upon its operating temperature. The methods of attack at low temperatures are distinctly different from those at high temperatures.

At low temperatures, hydrogen will diffuse atomically through the crystal lattice of steel until a barrier is reached that stops further migration. Laminations, unwelded blow holes and non-metallic inclusions are examples of barriers found in steel through which hydrogen cannot diffuse. When an atom of diffusing hydrogen reaches the surface of one of these discontinuities in the internal structure of the steel. it will quickly combine with another atom (on the surface of the barrier) and form molecular hydrogen. The molecular hydrogen is then trapped in the same manner that commercial hydrogen is contained in steel cylinders. As additional molecular hydrogen collects, the pressure increases and the steel blisters.

Undesirable high stresses will be localized in the neighborhood of a growing blister. The metal in the dome of each blister will be stressed above its yield point; the metal at its edges will be stressed at its breaking strength. Cracks develop perpendicular to the plane of the blister from either high shear stresses, or from high tensile stresses that have concentrated in bent metal fibers. It is alarming to observe that, regardless of the magnitude of the service load, some portions of a blistered structure will always be loaded at or above the yield strength of the steel.

The low temperature embrittling action of hydrogen has been explained by Zapffe and Sims¹² on the basis of submicroscopic faults that are present in iron and steel crystals. As molecular hydrogen forces these "disjunctions" open and the pressure increases, the metal becomes highly stressed triaxially. Metal stressed in this manner cannot flow and a superimposed stress causes brittle failure. Evans¹³ visualizes embrittlement as due to hy-

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drogen, that had been accommodated in the lattice, escaping during deformation and accumulating in "rifts" in the metal. The pressure thus generated causes the "rifts" to extend into cracks and the cracks to spread because the deformation at the edges of the cracks permits the escape of more hydrogen into the growing crack. Herres14 found that hydrogen embrittlement appeared to decrease when increasingly low testing temperatures were used or when the speed of testing was increased (from slow bending to impact testing) and concluded that embrittlement depended upon a precipitation reaction during straining and the reaction was limited by the rate of diffusion.

At high temperatures, hydrogen will also cause embrittlement.15, 16 However, the nature of the attack is quite different from low temperature attack. Hydrogen inside the steel will react (at high temperatures) with non-metallic impurities. Carbon is most reactive, but oxygen, sulfur, nitrogen and phosphorus will be attacked to lesser degrees. Methane and other insoluble gaseous reaction products will collect at grain boundaries under high pressures to embrittle and generally impair the steel's mechanical properties. Great improvements can be realized in steels designed for high temperature hydrogen service by making the carbon non-reactive. This has been accomplished by fixing the carbon in the form of the stable carbides of chromium, titanium, vanadium, etc.

While the mechanisms explaining embrittling are interesting, and satisfactory explanations are certainly desirable for a complete understanding, more factual data are still needed. Definite information is desired that will enable distinction between a steel that will not embrittle (if there are any) and a potentially embrittling steel. The effects of carbon content, alloy additions, hardness, condition of microstructure, cold work and state of stress on the behavior of steel in an embrittling environment are yet to be clarified.

EFFECTS OF HYDROGEN RELEASED DURING CORROSION

The greatest number of cases of embrittlement have been encountered in high carbon hardened steels. In some fabricating industries it has been felt that steels hardened only above Rockwell C 40 will be dangerously embrittled.17 Others consider embrittlement of little consequence if the carbon is below 0.35 percent and the hardness below Rc 35. Increasing carbon content in hardened steels, decreasing carbon content in normalized steels, and increasing cold work have all been reported to increase embrittlement. Yet laboratory tests have shown cold drawn SAE 1020 steel to embrittle under conditions that would not embrittle cold drawn SAE 1060 and SAE 1090 steels.18 Bolts having a maximum hardness of Rc 32 and a carbon content of less than 0.32 percent have failed in brittle manners in hydrogen sulfide service. The cold rolled SAE 1020 bolting previously mentioned, which failed in HF service, was hardened only to Rc 21.

Damaging Effects of Hydrogen As Determined By a Destruction Test of Blistered Vessel

Since blistering and embrittlement are so closely related, there appeared reasonable justification to question the ductility of steels in blistered vessels. It was reasoned that total embrittlement had not occurred since the layer of metal that deformed to form each blister exhibited some ductility. This layer usually elongated less than 10 percent, however, and was frequently cracked. A destruction test of a small pressure vessel was

selected as a method of assessing the total damage from hydrogen. It was felt that a test of this nature would show the over-all weakening of the structure through blisters reducing the wall thickness and concentrating stresses, and, it was hoped, would give an indication of the amount of embrittlement that accompanied blister-forming conditions.



Figure 18—Vessel tested to destruction after removal from service.

Bulged head and deformed steel at head junction indicate some ductility.

Consequently, a small badly blistered vessel was selected and removed from service. An attempt was made to minimize the amount of hydrogen that diffused out of the steel by testing the vessel rapidly and with as little delay as possible after it was removed from service. This vessel was 24 inches in diameter, 7 feet 6 inches long, with a

shell thickness of 3/16 inch. It was in low pressure service in a sour natural gasoline absorbtion plant as a make tank water leg. The vessel contained numerous closely spaced blisters, up to 2-inch length (Figure 18). Upon pressuring, the vessel failed by springing a leak at a 7/16 inch crack at the edge of one of

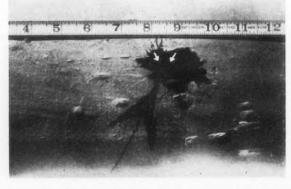


Figure 19—Failure in vessel tested to destruction (indicated by arrows) where vessel leaked at a crack along a blister.

the small blisters. (Figure 19).

The yield point had been exceeded only slightly as the permanent increase in circumference was less than 0.3 percent. The hoop stress in the shell fibers, calculated from the bursting pressure, was 35,800 pounds per square inch. This reduction in effective strength was equivalent to a metal loss of 22 percent of the shell thickness, (An

unblistered portion of the plate that failed had a tensile strength of 45,000 psi). Actually, there was no measurable metal loss and all measured thicknesses were within mill toler-

ances.

No embrittlement was detected. The flat heads bulged appreciably and the shell was severely deformed at the head attachment (Figure 18).

While this test did not show any embrittlement, low carbon steels used in pressure vessels are known to lose ductility when super-saturated with hydrogen.

Figure 20 shows the difference in necking behavior of two tensile specimens machined from the same blistered plate. The specimen at the bottom is in the as-received condition, the specimen at the top had been cathodically pickled in a five percent sulfuric acid solution (with 20 mg As/liter) for eight hours with a current density of one ampere per square inch.

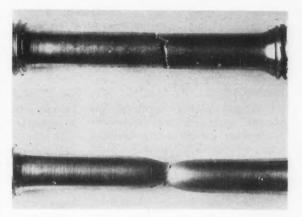


Figure 20-Behavior of two tensile specimens cut from same plate. Top sample was saturated with hydrogen by cathodic pickling before breaking. Bottom sample broken in "as received" condition. Note small blisters which developed during pickling top sample.

The physical properties of the two specimens are shown in Table II.

Reduction of area and elongation usually appear to be most sensitive to hydrogen embrittlement: tensile strength and impact resistance are less sensitive.

Control of Hydrogen Damage

One of the first steps in the control of hydrogen damage is to isolate the streams and locations in which blistering or embrittling conditions are present. Brittle failures of hardened steel springs and other steel components will serve to point out embrittling conditions. The actual presence of blisters will indicate blistering conditions. Since blisters are more frequently found on the inside surfaces of vessels than on the outside surfaces, a blister-free outside surface is not adequate assurance that the structure is not blistered. One way of locat-

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TABLE II
Physical Properties of Test Specimens

	Yield	Tensile	% Elong.	Reduction
	Point	Strength	in 2 Inch	of Area, %
As-received specimen	56,800	75,800	32.5	67.8
	58,500	76,300	10.0	15.9

ing blister-forming conditions in specific vessels, without trying to predict the action of the contents from its chemical analysis, is to install pressure gages in the tell-tale holes of nozzle and manway reinforcing pads.

Under blister forming conditions, hydrogen will accumulate under pressure in the artificial lamination formed between the shell of the vessel and any completely sealed pad welded to the shell. Although results have been somewhat erratic in some cases, probably due to thread leakage, pressure has developed under pads that have been attached to vessels that have blistered. No hydrogen has accumulated under pads in vessels in which blisters have not been found.

The maximum rate of pressure increase found was in the bottom manway pad of a 5000-barrel raw natural gasoline sphere where the pressure built up to 102 psi in 74 days. No pressure build up occurred during the first 30 days, but after that the increase was a steady rate. This non-uniformity of pressure increase may have been due to changes in corrosive conditions brought about by varying hydrogen sulfide content of the inlet stream. If this observation is correct, pressure gages attached to pads or pressure wells inserted in the vessel may have application in studying the effects of corrosion inhibitors added

to the stream without having to wait for actual blisters to develop.

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If blistered vessels are found by detailed inspection, repairs or replacements may be required depending upon the severity of the condition. Some blistered vessels have been removed from service and scrapped. The lower hemispherical head of the 12,000-barrel blimp previously described was replaced with a new head. Other vessels have been repaired by puncturing the blisters and chipping out and rewelding the cracks. The working pressures of some vessels have been reduced onehalf. Still others, operating at very low pressures, have not been repaired or derated.

Obviously it would be much better to prevent embrittlement and blistering than to continually repair and replace equipment that has been damaged. If it were possible to prevent atomic hydrogen from forming on the surface of steel, complete immunity to blistering and embrittling would be realized. Several methods appear to have merit in reducing hydrogen damage. They at least deserve consideration and possible further investigation.

Corrosion Resistant Materials

The use of high alloys has been found to have value in embrittled parts. The fact that the embrittled parts have been small, whereas the material that has been damaged

from blisters has been a tonnage product, may limit the consideration of more expensive corrosion resistant alloys to embrittling parts.

Protective Coatings

Metallic coatings of Monel and sprayed aluminum have been found to reduce embrittlement of hardened steel springs and valve plugs. It is easy to visualize that these coatings would show equally spectacular improvements if applied to equipment in blistering service. The cost of preparing the inside surface of large vessels, added to the cost of applying the metallic coatings, may be prohibitively high. Organic coatings that form an actual barrier between the metal and the corrosive liquid should have merit if a continuous coating of long lived material can be applied.

Use of a plain carbon steel inner shell offers other interesting possibilities. The effects of corrosion, embrittlement and blistering would be limited to this inner shell which would not be designed for strength purposes. The outer shell would furnish the structural strength and not be in danger of embrittling or blistering since it would not be in contact with the corrosive liquid. Holes drilled through the outer shell would permit escape of the hydrogen that diffused through the inner shell.

Improve the Homogeneity of Steel

It is quite definite that laminated plate is more likely to blister than plate that is not laminated. There is evidence that blisters form at highly segregated areas in preference to more homogeneous areas. Blistering service appears to demand specification of the cleanest commercially available steels that are free from laminations. More homogeneous steels should be obtained if fully killed steels are specified, such as those covered by ASTM Standards A201 or A212. rather than semi-killed or rimmed steels that may be furnished under ASTM Standard A285 (A70-A89), A283 (A10—A78), or A30. The specification of firebox quality instead of flange quality will insure greater freedom from laminations.

While blistered steels have been replaced by fully killed steels of firebox quality in the hopes of reducing the damage from blistering, the possibility of blisters developing cannot be ruled out. Blisters have been found in seamless pipe and one report of blisters developing in A201 plate in weak HF service has been received.

Control of Corrodent

If hydrogen sulfide could be eliminated from the stream, embrittlement and blistering should be minimized in petroleum processing equipment. The only exceptions might be in processes where acids are required. Complete removal of hydrogen sulfide would serve the dual purpose of removing the corrodent and eliminating a powerful "promoter."

As the amount of hydrogen that penetrates a metal is particularly responsive to the presence of small quantities of "promoters," it may be that certain inhibitors can be found that will be equally effective in supressing hydrogen absorption.

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Control of Diffusion

Control of diffusion through steel suffers from a lack of fundamental knowledge of the effects of alloying elements, carbon content and distribution, microstructure and cold work on the rate of hydrogen diffusion.

Unfortunately a completely clearcut solution to the problems of hydrogen embrittlement and hydrogen blistering cannot be given at this time. Some of the answers will require an advance of the general front of knowledge, and that type of advance is frequently slow. Using the information we have at hand, the best solution requires the concerted efforts of process and materials engineers in reducing the corrosiveness of the streams being processed and in improving the quality and corrosion resistance of the materials being corroded.

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Effect Of Atmospheric Corrosion on Maintenance and Economics of Overhead Line Hardware and Guy Strand * – Part 2

By C. J. Couy*

WHILE a great mass of general information is available on the deterioration of outdoor metals and structures, its application to any specific engineering task of structure design or maintenance requires considerable individual analysis and selection. The following is an attempt at some generalization of the problem.

In Part 1, it was shown that the service life of a structural unit is a simple function of its parameters and their rate of change:

$$L = \frac{1 - P}{R} + C \qquad [1]$$

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$$L' = \frac{P' - P}{R}$$
 [2]

Thus if the value for R and the variations of P' with time could be found, the problem of structure maintenance would be solved, P being a constant fixed by the design loading and original strength of the particular structural unit.

Units of Uniform Cross-Section Area Through Their Length.

It is well known that atmospheric attack is quite variable among similar units, even under controlled exposure. Also, while in ordinary exposure of similar structural units, under practically similar conditions, the attack is very non-uniform among units and usually varies over the various parts of the same unit, it will be enlightening as well as of use in the interpretation of the data in the solution of the practical problem of replacements, if certain simplifying assumptions of uniformity of attack are made and the effects of corrosive decay on the physical dimensions and, consequently, on the strength of units calculated.

The strength of any structure of uniform material, as long as this material suffers no physical or chemical change, is a function of its physical dimensions. Any cause resulting in the gradual diminution of these dimensions, therefore, acts toward the ultimate unfitting of the

Considerations of the Effect of Corrosion Decay on Structural
Strength

[★] A paper presented at the Annual Meeting of NACE in Chicago, Ill., April 7-10, 1947.

• Duquesne Light Co., Pittsburgh, Pa.

structure for its function; the period required for this effect constituting the life of the structure. If such a cause be assumed to act at a uniform time rate over the entire surface of the structure, certain of the effects on strength and the rates of these changes may be calculated.

Let:

r = Average annual corrosion rate, penetration inches per year.

r' = Maximum annual corrosion rate, penetration inches per year.

a_o, b_o, d_o = Original dimension.

Rw = Annual weight decay rate, fraction of original.

 R_T = Annual strength in tension decay rate, fraction of original.

R_B = Annual strength in bending decay rate, fraction of original.

R_D = Annual dimensional decay rate, fraction of original.

$$r_{\text{p}} = \frac{r}{d_{\text{o}}}$$
 and $r'_{\text{p}} = \frac{r'}{d_{\text{o}}}$

Then, for units of rectangular cross-section, uniform over their length (Figure 2), it may be shown that:

$$R_{W} = -2r \left(\frac{1}{a_{o}} + \frac{1}{b_{o}} \right) \qquad [3]$$

$$R_{T} = -2r'\left(\frac{1}{a_{0}} + \frac{1}{b_{0}}\right)$$
 [4]

$$R_B = -2r'\left(\frac{1}{a_o} + \frac{2}{b_o}\right) \qquad [5]$$

For circular or square cross-sec-

tions, equations 3, 4 and 5 assume the following simpler forms:

$$R'_{w} = -4r_{p} \qquad [6]$$

$$R'_{T} = -4r'_{p}$$
 [7]

$$R'_{B} = -6r'_{p}$$
 [8]

and by inspection

$$R'_{p} = -2r_{p} \text{ or } -2r'_{p}$$
 [9]

In the above derivations, terms containing higher powers of r or r' were neglected, being too small for structures of practical size.

Thus it is seen that, over the useable range of structural decay, the rates of annual decrease of these parameters would be practically constant, and their application would result in sloping linear characteristics.

In Figure 3 are plotted these characteristics for a circular or square cross-section, for $r_p = 0.0075$, indicating rates of weight and strength in tension decay twice the rate of dimensional decay; also, a rate of bending strength decay three times that of dimensional decay.

For thin sections, b₀ very small as compared to a₀, equations 3, 4 and 5 assume the form:

$$R = -K \frac{r}{b_o}$$
 [10]

indicating large rates of weight and strength decay, inversely proportional to the small dimension.

To determine the optimum cross-section for use in tension in corrosive environment, equation 4 may be differentiated with respect to a_0 . This results in an area $A_0 = a_0^2$,

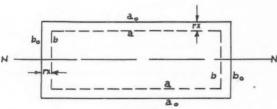


Figure 2

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[6] [7] [8]

[9] rms r r' for

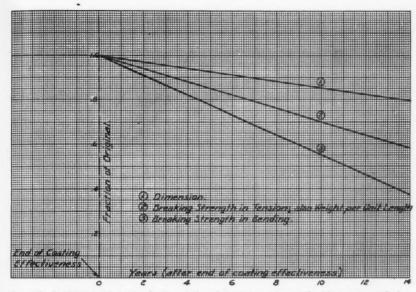
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CORROSION OF OVERHEAD LINE HARDWARE

Figure 3—Unidimensional structural unit variation of dimension and strength with time to weathering.

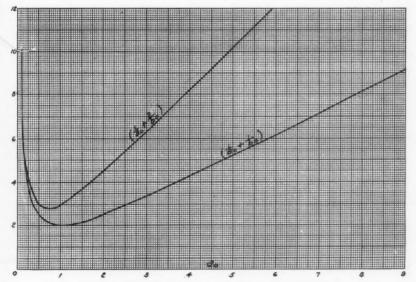


Figure 4—Optimum performance of rectangular cross-sections.

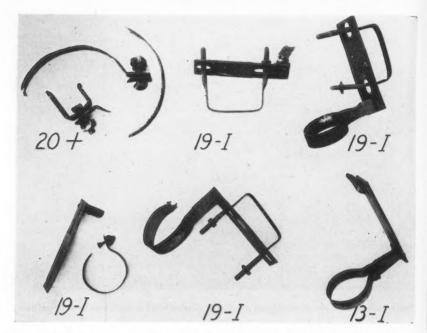


Figure 5—Lightning arrester bands and steel pole band. Numerals denote years in service, letter I, industrial exposure.

indicating a square section. Figure 4, a plot of function $\left(\frac{1}{a_o} + \frac{1}{b_o}\right)$ against a_o , when $a_ob_o = 1$, indicates the minimum at $a_o = 1$.

Similar operation with equation 5, to determine optimum cross-section in bending for corrosive environment, results in a section of a depth equal to twice its width or, $b_o = 2a_o$. In Figure 4 is plotted the function $\left(\frac{1}{a_o} + \frac{2}{b_o}\right)$ against a_o , for a section $a_ob_o = 1$, indicating a minimum at $a_o = \frac{1}{2}\sqrt{2}$.

This method has been applied in the determination of the replacement time, remaining life and probable service life of guy strand under any conditions of loading and the results used in the cost analysis and economic comparisons following.

Evaluation of Service Life of Units of Irregular Outline.

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While the calculations of the previous section would apply to the weak section, of corresponding outline, of this type of unit, it is usually impractical to attack the problem from that angle because of the difficulties involved in the location and measurement of that section while in service. Cases in point would be the oxygen concentration cell type of decay of bolts and pole steps at and inside the hole at the

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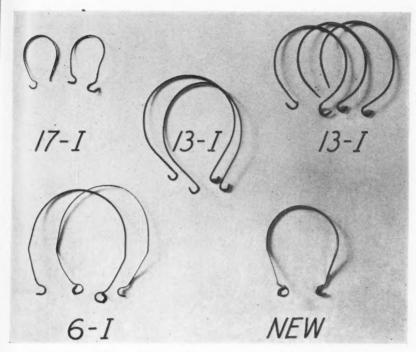


Figure 6-Aerial cable rings. Numerals denote years in service, letter I, Industrial exposure.

pole; also the pitting type, most irregular, attack on a sheet metal thimble clevis holding a live conductor dead-end.

To evaluate the probable service life of the lighter section and sheet steel items we may use equation

$$L_b = \frac{d_o - d}{2r} + C \qquad [11]$$

where

L_h = Service life, years.

do = Original thickness, inches.

d = Minimum permissible thickness, inches.

r = Rate of penetration, inches per

C = Life of the zinc coating, years.

The attack on this type of unit is

very non-uniform, (Figures 5 to 14, inclusive), because of partial shielding, shape irregularity, etc., so that severe pitting and perforation takes place at certain places while usually the unit is still capable of functioning.

If it is assumed that a unit be considered for replacement when severe pitting or perforations appear on it, equation 11 would reduce to:

$$L_h = \frac{d_o}{2r} + C \qquad [12]$$

Table V has been computed on this basis, and indicates a very reasonable agreement with the condition of line hardware samples of

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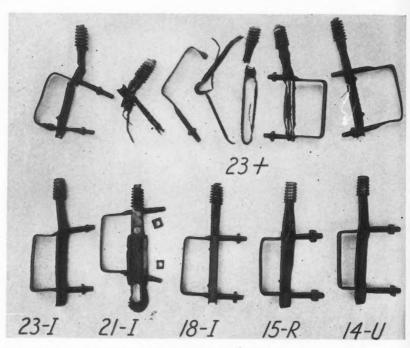


Figure 7—Double channel, pressteel and forged low-voltage insulator pins. Numerals denote years in service, letters I, U, R industrial, urban and rural exposure.

TABLE V

Evaluation of Probable Perforation Time of Typical Zinc Coated Steel Line Hardware. Pittsburgh, Pennsylvania

	Sheet Metal Gage	Thick- ness Inch	Steel Perfor. Time—Years		Toral Perfor. Time—Years			
MATERIAL			Sev.	Avge.	Sev.	Avge.	Remarks	
Cross Arm Braces (diagonal and flat)	(equiv.)	0.25	11.4	17.1	21.4	30.1	Checks with condition of specimens.	
Cross Arm Braces (vertical and U.) L.V. Pin straps	7 (equiv.)	0.1875	8.5	12.8	18.5	25.8	Checks with condition of specimens.	
Secondary Racks (points). Thimble clevis	9	0.1563	7.1	10.7	21.1+	24.7+	Checks with condition of specimens.	
Aerial Cable Rings	10 (equiv.)	0.1406	6.4	9.6	11.4	17.6	Pessimistic	
L. V., D. C. Pins, L. V. Light- ning Arrester Band	11 (equiv.)	0.125	5.7	8.5	15.7	20.5	Slightly pessimistic	

Penetration rate for severe area, 0.011 in./yr.. see Table I. Penetration rate for average area, 2/3 (0.011) in./yr., assumed. Total perforation time derived by addition of zinc coating life from Table III to perforation time of steel.

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Figure 8—(right) Secondary racks. Numerals denote years in service, letter I, industrial exposure.

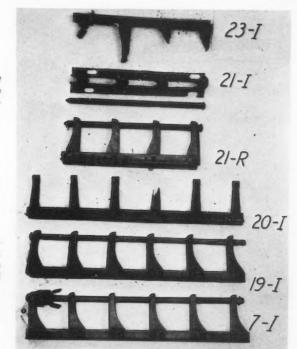
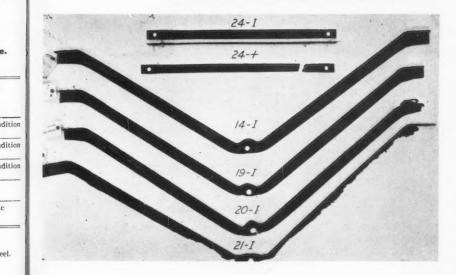
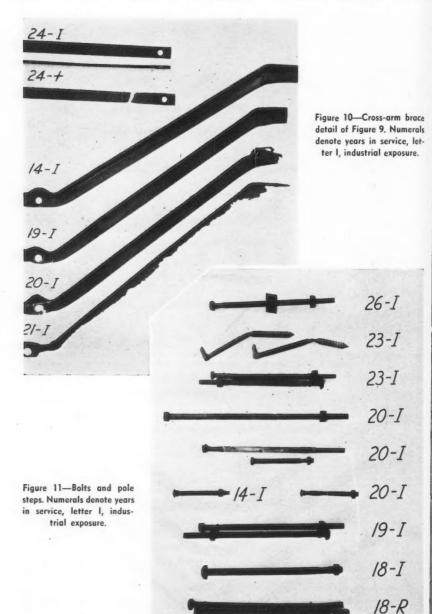


Figure 9-(bottom) Crossarm braces; flat and angle. Numerals denote years in service, letter I, industrial exposure.



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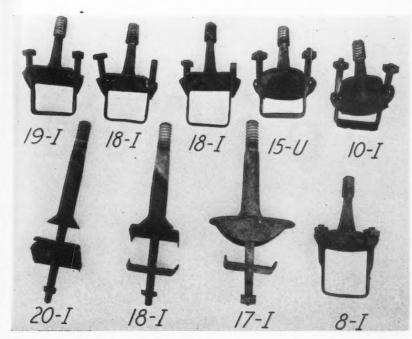


Figure 12—Forged high- and low-voltage insulator pins. Numerals denote years in service, letters I and U, industrial and urban exposure.

known age collected mostly from industrial areas. This table, indicating probable life ranges of 11 to 22 years for severe exposure and 18 to 30 years in average urban exposure, emphasizes the need for line hardware of longer durability, matching the probable life of the preservative-treated pole on which it is installed, if long range maintenance programs are to be effectuated.

Because the mensurable parameters, including age, of these units are not practicable for use in the determination of the correct replacement time, it would seem that empirical replacement standards would

have to be developed. This could most readily be accomplished by testing typical units in various stages of decay to destruction, and recording the results, possibly photographically, for use in training the maintenance force. This part of the work has not been attempted.

The heavier, malleable iron and copper-bearing forged steel units such as strain and suspension clamps, hooks, strain insulator caps, etc., because of their larger section as well as slower corrosion rates, perform very satisfactorily.

With the information as outlined in the preceding sections available, the remaining life of any unit could

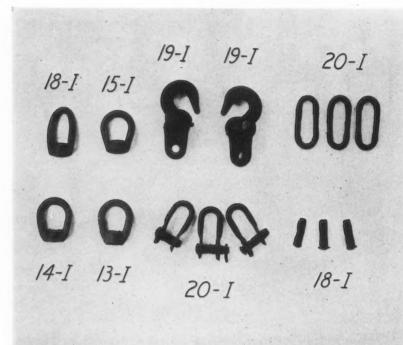


Figure 13—Forgings: eye nuts, links, clevises and cotter pins. Malleable: hooks and sockets. Numerals denote years in service, letter I, industrial exposure.

be closely defined. To apply this information in the operation of any structural system it would only be further required to periodically inspect the units or assemblies to determine if minimum required parameter has been reached or sufficiently approached.

Since the life, as well as the age, of all the units that go into the make-up of distribution plant assemblies are ordinarily not equal, it is obvious that maximum permissible decay of each will occur at different times. If no waste is to be incurred, therefore, it appears that replacements should be made at various times. The determination of the economical inspection period, then, is an additional requirement in the development of a routine maintenance program.

Where the cost of units is relatively high, their number relatively small and, therefore, inspections relatively frequent, it is possible to make the necessary replacements at, or very near, the correct time with little or no loss in life. To effectuate such a replacement program a proper individual system of records for each unit or assembly is

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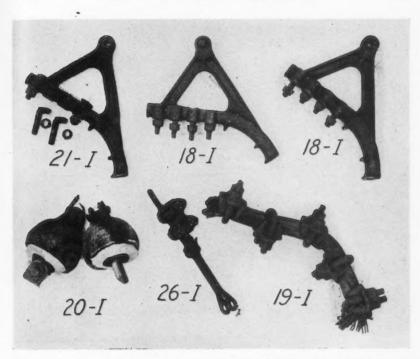
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CORROSION OF OVERHEAD LINE HARDWARE

Figure 14—Forgings: J-bolts, wire rope clips, insulator caps. Malleable: strain clamp bodies. Numerals denote years in service, letter 1, industrial exposure.

required. In an electric distribution system this is the case with items such as wood poles.

For the cheaper and much more numerous small items, such as small galvanized hardware, guy strand, etc., the necessary individual records to effectuate such a program would be too cumbersome and expensive.

An economical inspection period must, therefore, be instituted whereby minor unit replacements can be made at the time of inspection by the inspecting personnel or, shortly thereafter by others if more advantageous, so that the resultant loss in equipment life plus inspection cost be a minimum.

Let:

- k = Total in place cost of the average pole including hardware and guys, but excluding insulators and con-
- ductors, dollars. k' = Total in place average cost of hardware and guys per pole, dollars.
- k" = Total average labor inspection cost per pole, including records and supervision, dollars.
- L = Average life of hardware and
- guys, years. T = Inspection period, years.
- c = k'/k p = k''/k
- Then the annual labor inspection cost per pole would be

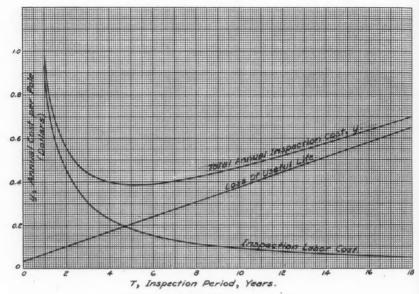


Figure 15—Economical inspection period.

$$y_1 = \frac{pk}{T}$$
 [13]

Assuming equal age distribution of equipment over a period of L years, the annual loss per pole due to premature replacement of hardware because of an inspection period T years, instead of yearly, would be

$$y_{m} = \frac{ck}{TL^{2}}(1+2+3+...+T) = \frac{ck}{2L^{2}}(T+1)$$
 [14]

The total annual cost per pole with an inspection period T, then, would be

$$y = \frac{pk}{T} + \frac{ck}{2L^2}(T+1)$$
 [15]

Differentiating and equating to zero for minimum

$$\frac{dy}{dT} = \frac{-pk}{T^2} + \frac{ck}{2L^2} = 0$$

and the economical inspection period is

$$T = \left(\frac{2pL^{\prime 2}}{c}\right)^{\frac{1}{2}}$$
 [16]

Figure 15, indicating optimum inspection period, slightly over 5 years, is the graph of equations 13, 14 and 16, using average constants from our overhead system. Material and labor costs are as of 1944, and the cost experience of an inspection of 1022 poles, of an age range between zero and 20 years.

EDITOR'S NOTE: The third and final part of Mr. Couy's article will appear in the June edition of Corrosion.

Organic Coatings for Corrosion Protection A General Discussion*

By G. W. Seagren*

PROTECTION of metals from corrosion is a continuous problem throughout industry. Methods of preventing destruction of metals by the corrosive effects of the environments in which they are used are various; but only the application of organic coatings and the characteristics which are desirable in such coating systems are considered here.

Coating Must Be Continuous

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Organic coatings are effective means of preventing the corrosion of metals, primarily because they serve as protective barriers between the metal to be protected and the environment in which the corrosion will occur; and the effectiveness of a coating system for this purpose is relative to four characteristics. The coating must be continuous: it must resist the spread of corrosion from uncoated areas: it must have a high degree of impermeability; and, lastly, it must not itself be degraded by its environment. Each of these desirable characteristics is considered separately.

A coating, to give effective protection, must be continuous. In actual practice, it is very difficult to apply a coating system so as to form a continuous film, even with the best coating system available; and, if the coating film is produced free from discontinuities initially, there is always the possibility that the coating may be accidentally injured during its service life. This problem of producing and maintaining a continuous coating creates the necessity for selecting coatings which have suitable properties, and for exercising great care in applying them.

No All-Purpose System

No one coating system will serve equally well for all uses. For some applications, thin films are required; for others, heavy coatings. For example, when organic coatings are used to separate highly corrosive materials from corrodible metals, the coating films must be thick and resistant; and, as a precautionary measure, such films should be carefully tested for discontinuities before being exposed to use.

One of the best ways to keep the number and size of discontinuities in a coating to a minimum is to apply more than one coat. A single-

^{*}A paper presented at the Symposium on Modern Metal Protection in Cleveland, Ohio, Sept. 27, 1947.

^{*} Administrative Fellow, Stoner-Mudge, Inc., Multiple Fellowship on Protective Coatings, Mellon Institute of Industrial Research, Pittsburgh, Pa.

coat system is seldom used except where the conditions of use are only mildly corrosive. In most cases, at least three coats are recommended; and, for extremely corrosive conditions, five or more. Discontinuities in any one of a series of coats will not usually coincide with those in preceding coats; thus, the number of accidental discontinuities which remain in a finished coating is decreased considerably with each succeeding coat.

Spread of Corrosion from Uncoated Areas Must Be Minimized

Finished coatings, however, frequently are not continuous initially, and discontinuities can be formed by accidents to a paint film during its service life. The presence of discontinuities, however caused, is the reason why the second requisite characteristic of a good coating is important, that is, the ability to resist the spread of corrosion from areas exposed by discontinuities and the enlargement of the discontinuities themselves.

Coatings are not always weakened or destroyed directly by their environment. Frequently they are degraded by products of corrosion reactions near or under them.

Reactions Electrochemical in Nature

Usually such reactions are electrochemical in nature.

In an aqueous environment, an area of bare metal which is exposed by an opening in the coating is anodic; the metal adjacent to such an area and beneath the surrounding coating is cathodic. As the electrochemical reactions proceed, the cathodic area becomes progressively

alkaline; and the coating, if not resistant to this alkali, will deteriorate. Thus the corroding area is increased. The greater the conductivity of the electrolyte between the two electrode areas, the greater will be the electrochemical reaction and the amount of alkali formed.

Degradation of coating films by alkali can be prevented or kept to a minimum only by using coating systems which are sufficiently resistant to the alkaline products of these reactions. Destruction of coatings as a result of this type of reaction is found frequently on painted metals corroding in sea water.

Pretreatment Commonly Utilized to Prevent Under-Cutting

Discontinuities in coating films can permit the progress of still another reaction which is not a degradation of the film itself but which, nevertheless, destroys the efficiency of the coating; that is, under-cutting. Undercutting is that process by which a coating is loosened from metal adjacent to exposed areas by corrosion of the metal *under* the coating. This can usually be prevented if the metal surface is treated chemically before the coating is applied.

Pretreatment of metal to prevent under-film corrosion is common practice. It consists of producing on the surface of the metal, by reaction with the metal itself, a suitable inert compound of the metal, for instance, the oxide or the phosphate. Such a coating is called a conversion coating; and the type to be preferred depends upon the metal to be protected. For steel, the conversion coating is usually iron phosphate, although

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the iron oxides also are used for some applications. The phosphate treatments are used more generally than the oxide processes; but the trend in metal pretreatments for aluminum has been toward the use of oxide surface-layers rather than the phosphate conversion coatings.

Various pretreatments for metals are available commercially; but the two most commonly used are Parkerizing and Bonderizing. These processes form coatings which are essentially iron phosphate and which vary in thickness and in crystal sizes.

Early pretreatments for metals had a decided disadvantage in that the conversion coatings which they produced were brittle. For this reason, metals could not be pretreated when it was necessary to fabricate the metal after a coating was applied. This difficulty has been overcome within the last few years by the development of pretreatments which produce conversion coatings that are sufficiently flexible to permit fabrication of the pretreated metal after it has been coated.

Mechanical and Chemical Adhesion

Restricting corrosion to areas of bare metal by means of organic coatings is also a function of the adhesion of the coating itself to the surface of the metal. Adhesion of a coating is basically of two kinds: mechanical and chemical. Mechanical adhesion, which is mainly "keying" or locking, depends on the character of the metal surface, because smooth surfaces provide poorer mechanical adhesion than do rough surfaces. Chemical adhesion is a function of the coating material. In the

resin phase, a coating material consists of very large molecules which may be long chains, closed chains, cross-linked chains, or any combination of these types. These resin molecules vary in size and shape, and they have various molecular fields of force about them. Attraction is stronger between a metal surface and strongly polar groups of molecules; so coatings which contain such molecular groups adhere more firmly to metal than do coatings in which the groups are only weakly polar. Coatings of non-polar resins usually have very poor adhesion to metal surfaces.

It is generally accepted that attraction of polar resin molecules to metal is more important in providing adhesion of coatings than is mechanical "keying" or locking.

Note of Caution Concerning Application

A note of caution is included here concerning the application of any coating. To take the fullest advantage of the chemical factors which provide adhesion, it is necessary that the surface to be coated be clean, because a film of grease or dirt on the metal surface to be coated can seriously diminish the attraction between the molecules of the coating and the surface of the metal or the metal compound.

High Degree of Permeability

The third important property of a coating for preventing corrosion of metal is permeability. Permeability of a coating may be defined as the rate at which a gas or liquid will diffuse through the organic film to the surface of the metal beneath. There are no organic coatings which can prevent completely the diffusion or permeation of moisture, even though there are no gross discontinuities in the applied film; but all coatings are not equally permeable. The rates of permeation through coatings vary over a wide range: from less than one to more than 300 milligrams of moisture in 24 hours through a one-square-inch area of film one mil thick.

It is comparatively easy to select a coating which has the least permeability; but, unfortunately, such a coating may be very poor in other important properties, such as flexibility, chemical resistance, ease of application, etc. Thus, the most impermeable coating must frequently be rejected for another which has other necessary qualifications.

Minimizing Effect of Moisture

Complete exclusion of moisture cannot be attained; but the effect of moisture can be minimized by one of the following methods:

First, permeability can be reduced by special pigments. Pigments, such as aluminum, which have a flaky structure, reduce permeability by lengthening the path which moisture must travel through the film from the outside surface to the underlying metal.

Second, special pigments, by their oxidizing action, render the permeating substance less corrosive. Red lead and zinc yellow are familiar examples of oxidizing pigments; zinc oxide and basic lead chromate are effective probably because of their alkalinity.

Third, metal pretreatments reduce the corrosivity of the metal surface by producing, on the surface of the metal, a compound of the metal which is less reactive than the metal itself. This method of combating the effect of moisture has already been referred to in connection with the prevention of underfilm corrosion.

Lastly, pigments may retard corrosion by being anodic with respect to the metal protected. Tests have indicated that high loadings of zinc dust or aluminum powder in organic vehicles produce what is, in effect, cathodic protection of underlying steel surfaces.

Coating Must Resist Attack by Environment

For effective prevention of corrosion, an organic coating must have a fourth property: it must resist degradation by its environment. This fourth property is contributed chiefly by the constituent film-forming or resinous substance, which must be selected from a very large and rapidly expanding group of materials. Actually, the selection and adaptation of suitable resins to specific needs is such a critical task that it should be assigned to individuals whose experience in the field of resin chemistry has been wide enough to qualify them as experts.

Ever Increasing Number of Natural, Synthetic Resins

It is not possible to discuss adequately and to define the complexities of the various kinds of natural and synthetic resins. Instead, the bare statistics of their increasing number will indicate the variety of these materials and the complicated lish ica Pa ors

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problem of selection which this variety presents.

In 1937, H. A. Gardner listed 260 synthetic resins. This list was published in the eighth edition of "Physical and Chemical Examination of Paints, Varnishes, Lacquers, Colors." Two years later, in the ninth edition of the same publication, Mr. Gardner listed 380 resins. In August, 1946, in Circular No. 716 of the National Paint, Varnish and Lacquer Association, Inc., Mr. Gardner classified more than 785 resins in the following nineteen groups:

Resin	Vui	nber
Urea		13
Melamine		
Other amines		4
Vinyl		19
Acrylic		
Styrene		
Coumarone and Indene		
Petroleum		5
Chlorinated		15
Alkyd	2	74
Maleic		
Phenolic		
Ester gum		32
Other rosin esters		
Rosin-modified		
Limed rosin		29
Terpene		26
Natural resins		
Miscellaneous		
Total	7	85
A.C.C.		CC

Also in 1946, the Plastics Catalogue Corporation published a list of the representative plastics used in organic coatings in which these materials were classified in 36 groups. Each of these groups could be subdivided into an extremely large number of variants.

Service in the Field

In research, laboratory data are accepted as valid bases for evaluating coatings; but it is also important to learn what kind of service organic films give in practical use. Recent applications are illustrations of this.

In 1940, steel boiler tubes coated with a phenol formaldehyde-type coating were installed in two low-pressure (15 pounds per square inch) boilers. Outside the coated tubes, the water temperature was 220° F.; inside the tubes, the average temperature of the flue gas was 675° F. The boilers were opened and inspected annually. At the sixth-year inspection, there was no evidence of coating deterioration on the outside—i.e., the water side—of the pipes.

Results Encourage Large-Scale Production

On the inside, where the coating was in contact with the hot flue gas, there were only slight evidences of flaking; and these failures were believed to have been caused by the wire brushes and swabs which were used weekly to remove accumulated soot. The performance of this coating is remarkable when it is recalled that, in this type of installation, uncoated boiler tubes usually last through only one heating season.

This test and others similar to it have aroused the interest of industry to the extent that several of the large manufacturers of steel tubing are preparing to market coated tubing in commercial quantities, for use in condensers, heat-exchangers, boilers, and in straight pipeline installations where, previously, only nonferrous tubing could be used.

Another durable coating was severely tested in the Ohio River. In 1938, the Pittsburgh District Office of the U. S. Corps of Engineers initiated controlled paint tests on some of the gates in one of the Ohio River dams. In 1946, after eight years of immersion, four of the paint systems were still in excellent condition. The outstanding coating of the group was based on a phenolic vehicle and was pigmented with zinc dust and zinc oxide.

Survives Tests at Panama Canal

This paint was tested again similarly in 1941, when it was one of a series of test paints applied to one of the gates of a power dam in the Susquehanna River, in Pennsylvania. At the end of five years' immersion, this phenolic paint, pigmented with zinc dust and zinc oxide, was in perfect condition.

A paint system similar to this was applied to the four emergency gates installed in the Panama Canal. At the end of five years' service, the coating was reported in satisfactory condition.

All-Vinyl System

During the war, Bakelite Corporation developed an unusual coating system for the U. S. Navy. This was an all-vinyl system for protecting ships' bottoms from corrosion and from fouling. The primer for this coating is Bakelite's wash-primer, WP-1, which is applied in thin coatings about a half-mil thick. This primer is a combination of a vinyl resin, phosphoric acid and a zinc-

chromate pigment; and it is of special interest because it will tolerate the presence of a film of water on the surface of the metal to which it is applied. When dried and aged, it develops excellent adhesion to all metals and has special merit as a primer for galvanized iron and for magnesium alloys.

The end of the war brought a demand for an entirely different type of protective coating. Protective coatings have been thought of, generally, as paint systems that adhere closely to the metal to be protected. The new coating had to be a removable "envelope" of moisture-resistant resin which would prevent the corrosion of assembled machinery or equipment during extended periods of storage.

System Developed

Suitable cover-all films were developed to meet this need. They are solution formulations of vinvl resins, applied by spraying. When sprayed, these formulations become long threads of resinous material and form a spider-web-like cover which bridges irregular contours of structure. Then, over the basic network, a conventional formulation is sprayed, and this second formulation provides a low-permeability finish coat. In addition to the coating, another precaution against corrosion is taken: a desiccant is enclosed with the coated structure, to maintain a low relative humidity within the envelope and thus prevent damage to the metal which might result from slow diffusion of water vapor through the organic covering.

Prevention of corrosion of metal in moist and gaseous environments stantect periodic this latic mar who surv pain spec cial Pain

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is not the only use for organic coatings. In some industries, steel structures are subjected to extremely high temperatures, and the substances which coat them must protect the steel during and after these periods of extreme heat. To meet this requirement, numerous formulations have been marketed, but many are of doubtful value. The whole group of these coatings was surveyed by technologists in the paint field; and the findings of these specialists were published in the December, 1945, issue of the Official Digest of the Federation of Paint and Varnish Production Clubs. The following two excerpts from that report should serve to indicate the temperature limits for resinous coatings and the difficulties to be overcome in developing better coatings of this type:

"Up to the time of the war, no satisfactory finish for surfaces heated above 600° F. for any length of time had been developed or marketed, but each investigator claimed moderate success for his specific formula.

"All investigators concurred in stating that films composed of organic binders begin to decompose below 600° F. and disintegrated to an extent that rendered them valueless between 600 and 800° F. under prolonged heating."

Some of the more successful hightemperature paints are pigmented with aluminum. At temperatures which cause the organic matter to decompose, this metal pigment tends to become alloyed with the surface of the metal, or at least to form a bond with that surface. The result is that, after the organic film has failed, protection against corrosion is provided by a layer of aluminum on the surface of the steel.

Silicone Resins

The most promising recent developments in the field of heat-resistant coatings are the silicone resins, which are organic silicon polymers. Exposure data on these substances seem to support the belief that the silicone resins will provide adequate protection for appreciable periods at temperatures up to 600° F. Above 600° F., their usefulness for protection decreases. However, if the main purpose of the coating is decoration only, rather than corrosion protection, coatings made from silicone resins will withstand temperatures somewhat higher than 600° F. White coatings made with silicones are quite resistant to yellowing; and aluminum-pigmented silicones have been baked at temperatures up to 1000° F., without visible evidence of deterioration. Unfortunately, the silicone coatings which were baked at temperatures above 600° F., failed to provide adequate protection against corrosion when exposed to the atmosphere.

Some of the factors of primary importance in protecting metals by organic coatings have been considered. Others, which do not pertain directly to the coatings themselves, are of equal importance. Applicability is a problem, for just any coating cannot be applied to any surface. Coating systems may be hazardous to the health of workmen who apply them and, in the case of linings for food containers, to the health of individuals who use foods

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marketed in coated packages. Unsuitable coatings for containers can affect the flavor of packaged foods and may even be toxic; and serious damage by explosion and fire can be caused by volatile solvents during application of coatings.

Availability may make it necessary to use a poorer, instead of a better, coating, if some component of the better system can be obtained only in too-small quantities. Even the economic factors of cost of material, cost of application, etc., must not be overlooked.

Many organic coatings have failed to give satisfactory protection against corrosion simply because all the factors which accelerate corrosion, or which make it possible to coat a surface efficiently are not understood. Unlike metals in contact with each other in structures submerged in water constitute an electrical unit which will accelerate the corrosion of one of the metals unless both metals are effectively coated. If only the corroding metal is coated and if the coating is not perfect, galvanic reaction is localized and intensified at breaks in the coating film; and deep pitting or even perforation will occur.

Another obstacle to good coating applications is complex structural

designs; for it is practically impossible to coat well a surface that has narrow crevices and sharp edges, if only because coatings flow away from edges and because solvents which must escape from paint films in crevices inevitably leave discontinuities in the cured film. Metal equipment and machinery which must be protected by coatings should be designed to have as smooth a profile as possible, with a minimum of complicating surface details.

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These are but a few of the environmental elements which can interfere with the efficient application and satisfactory performance of a coating film. It is not necessary that a design engineer be familiar with all types of organic coatings; but it is highly desirable that he have an understanding of the fundamental corrosion processes and of the mechanics of corrosion prevention by means of organic coatings. Equipped with such information, the engineer will consider corrosion prevention as another problem in design. Too frequently corrosion protection is only a necessary afterthought. Many of the difficulties with which organic coatings technologists are confronted might have been avoided on the drawing table.

Salt Water Corrosion of Ships*

By R. A. Pomfret* and L. M. Mosher**

CALT WATER corrosion is of primary concern to ship designers, builders, and operators, because control of this damaging action is essential to the economical operation of the modern steel vessel. The fundamental principles involved are fairly well understood by engineers in each of the above categories, and it is usually through oversight or through failure to recognize a given set of conditions as being favorable to accelerated corrosion that unusually high corrosion rates are allowed to become established. This article attempts to review the fundamental principles which are applied in modern shipbuilding practice to minimize corrosion damage, and gives examples of the consequences when these precautions are not observed.

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under a periodic repainting schedule, they eventually become adequately protected before any significant damage occurs. However, these areas serve as focal spots for corrosion when abnormal conditions, tending to accelerate the corrosion rate, arise. Probably the most potent of these abnormal conditions is electrolysis caused by stray currents.

Stray Current Corrosion

Strav current corrosion is most likely to occur when insufficient attention is paid to the grounding of electrical equipment used aboard ship which is supplied with power from the shore. If insufficient shipto-shore ground cables are used for the current involved, some of the current will flow from the ship, through the water, to the shore, carrying ions into solution. The electrical resistance of the paint film forces the current to leave the hull preferentially through scratches or other defects in the paint coating, thus concentrating the corrosion at these points.

Figure 1 illustrates the damage which may be caused by this type of corrosion when rather heavy

Hull Corrosion

Normal corrosion of the steel hull is controlled by the use of proper materials and the maintenance of an adequate paint film. Improperly coated areas which sometimes occur are not normally troublesome, since

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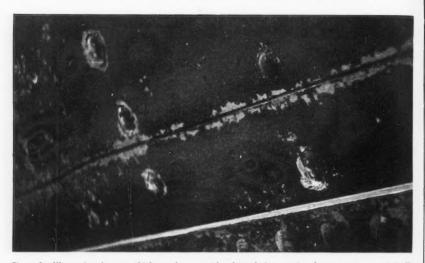


Figure 1—Illustrating damage which may be caused by electrolytic corrosion. Long gouge was originally a scratch in paint film which occurred during launching. Note corrosion of rivet points where paint film is thin.

welding currents are improperly grounded. Corrosion of this type is sometimes incorrectly attributed to some inferior quality of the material, but when the electrical conditions are corrected and the damaged area is properly painted, further corrosion ceases.

Ground cables should have an area of at least one million circular mils for each 1000 amperes current being supplied to the vessel from the dock. A typical satisfactory grounding system consists of three one-million circular mil cables attached to the ship, forward, amidship, and astern. Additional cables are run directly from the grounding point to the ship when the current load exceeds 3000 amperes, in order to maintain the proper area-current ratio. Ground cables are made no longer than necessary and checked at

regular intervals to insure maintenance of good electrical contact.

When ships are at a pier for extended periods of time, or when unusually heavy currents between ship and pier are involved it is the practice in some shipyards to take periodic voltage-drop readings between ship and water by measuring the voltage differences between the hull and a plate of similar composition suspended in the water near the hull. Experience with this method has shown that voltage differences greater than 0.25 volt call for further investigation of the electrical circuits. In this respect, attention is drawn to the fact that dangerous potentials are those in which the direction of current flow is from the vessel to the reference plate. It is necessary, therefore, that the direction of current flow or polarity be ol. 4

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ascertained. One additional precaution: It is advisable that potential measurements of this type be made immediately after connecting the test plate to the vessel, since the flow of any considerable current from the ship to the plate may result in polarization of the latter, such that the original potential may be reduced below the level which indicates danger.

Securing Accurate Measurements

These readings give only an instantaneous indication of the electrical conditions, however, and may be misleading if made at a time when the electrical load is low. This disadvantage may be overcome by use of special test plates which are valuable for the indication of the cumulative effects of current leakage. These plates can be prepared from steel, approximately one-foot square, painted with marine primer. The paint film is scratched near the center of the plate so that any corrosion which occurs will be concentrated in this area.

The test plates are suspended from the hull of the ship into the water at several points along the length of the ship. They are installed in pairs, one of each pair being suspended by a copper cable (electrically connected to hull) and the other being suspended by rope (insulated from hull). The cumulative effect of any electrolytic corrosion may then be determined by measuring the difference in depth of corrosion at the scratches in the paint film of the non-insulated panel as compared to that shown by the insulated panel, which would be considered as normal corrosion.

Stray current corrosion may also occur when land-based d-c electrical systems, such as electric railways or travelling cranes, are improperly grounded. If this equipment is grounded in such a way that the ground current may pass through a body of water, then any ship in that water may be subject to accelerated corrosion at points where the ground current leaves the ship and re-enters the water.

SALT WATER CORROSION OF SHIPS

Galvanic Corrosion

A second type of accelerated hull corrosion may arise from a combination of circumstances involving the presence of mill scale on the hull plating in conjunction with inadequate paint protection. Under such conditions, galvanic corrosion will develop as a result of couples between the mill scale and exposed steel and between the mill scale and rivet heads or welds, unless the latter are definitely cathodic to the mill scale, which usually is not the case.

Example of Phenomena

The following example which recently came to the attention of the authors will better explain this phenomenon:

Costly corrosion troubles were encountered on the underwater hull of a cargo vessel built not long ago at one of our yards. Prior to launching, this vessel was coated with a single coat of marine primer and single coats of standard anti-corrosive and anti-fouling paints. After a fitting-out period of four months, the vessel was drydocked prior to delivery, at which time the vessel was spot primed where necessary



Figure 2—General deterioration of rivet points and shell. Rivet points (Arrows 1). White deposits (Arrows 2). Corrosion of plate away from rivets at breaks in mill scale (Arrows 3).

and then received one complete coat of the same standard anti-corrosive paint followed by a complete coat of anti-fouling paint. At this docking, no sign of unusual corrosion activity was in evidence.

Seven months later, however, after an extended cruise in India and an enforced lay-over of 44 days in New York, the vessel was again dry-docked, to expose evidence of serious corrosion, principally on rivet points, but also on plates, on rudder and stern frame castings and on some welds. Corrosion in the rivet points can be seen in Figure 2, a general view, and Figure 3, a close-up. The

corrosion had been vigorous, reaching a maximum depth of about 0.10 inch in some areas. Obviously, this corrosion was abnormal, being in the order of 30 to 40 times the expected normal corrosion rate for steel immersed in sea water. An investigation of its cause or causes was launched immediately.

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A careful inspection of the hull showed several interesting facts. First, as much as 50 percent of the hull in certain areas was devoid of paint. In addition, there was considerable evidence of blistering and peeling of the remaining paint. Secondly, there were definite brownish-

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Figure 3-Enlargement of corroded rivets shown in Figure 2.

white patches of sea salts sometimes called "Cox" deposits which, when removed, disclosed mill scale beneath. Under sea water immersion, such deposits form on cathodic surfaces, hence, in the absence of externally applied currents, give telltale evidence of the presence of galvanic activity.

As an added clue, the rivet points on which there was widespread damage showed a fairly consistent pattern in the form of initial attack to one side of the point, spreading fanwise across the remainder of the rivet (Figure 4). In way of explanation, it is customary when driving rivets, for the riveter to chip away

excess metal from the point. This chipping is done after the rivet has cooled to a dull red or even black heat just prior to the final driving. As would be expected, a normal scale forms on most of the point of a hot driven rivet but the area chipped may be substantially scalefree. This chipped area is usually off to one side of the point. When exposed to sea water because of inadequate paint protection, the existence of a potential gradient between the essentially scale-free chipped area and the remaining scaled area as well as the surrounding mill scale on the hull plating, would tend to set up galvanic corrosion. Since the cus-

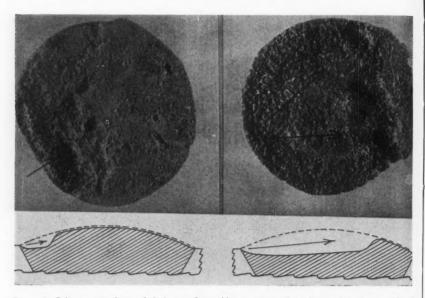


Figure 4—Enlargement of corroded rivet surfaces. Note concentration of corrosion at one side of rivet (left) proceeding fanwise across the rivet point (right).

tomarily used carbon steel rivets are anodic to the riveting scale as well as the plating mill scale, galvanic corrosion, starting at the chipped area, would be expected.

Based on these observations, it was concluded that (1) the extensive corrosion on this particular vessel was basically due to the absence of an adequate paint film and (2) that accelerated corrosion resulted from galvanic activity between the exposed mill scale and areas of bare steel such as rivet points, welds, scratches, etc.

Aside from mill scale difficulties, galvanic corrosion is frequently encountered on areas of the hull in close proximity to the customarily used manganese bronze propellers. Electrical contact between the pro-

peller and hull is made by way of the shaft, line shaft bearings, and shaft couplings which contact is unavoidable from a practical point of view.

In an attempt to decrease this type of attack, it is often recommended that zinc waster pieces be attached to the hull in way of the propeller. These wasters are slabs of zinc of variable size which are bolted to the steel hull structure. It has been our experience, however, that such wasters fail of their purpose, probably because of the restricted zone of influence that they exert. Drydock inspections have shown vessels on which no such wasters are installed fail to show any more extensive corrosion than those with zinc wasters.

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corrosion, vessels when under way are subject to a type of corrosion which appears exclusively on leading edges, such as the forward edges of the stem casting, lapped plates, bilge keels, and other protrusions. This process can best be described as a scrubbing action, and undoubtedly arises from a combination of circumstances, including abrasion from materials floating in the water, along with such water effects as velocity, impingement, and turbulence. Typical erosion of the leading edge of a bilge keel is shown in Figure 5, and Figure 6 shows similar effects on the forward edges of lapped plates.

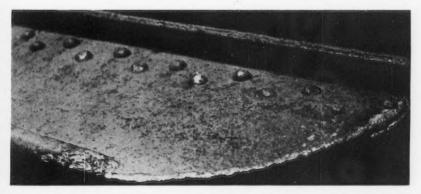
Corrosion of Machinery Installations

Materials entering into the construction of marine machinery installations are numerous and possess varying degrees of resistance, both to salt water corrosion and the factors which tend to increase normal corrosion rates. The essential accelerating factors which the designer must keep in mind are water temperature, water velocity, impingement attack (associated with turbulence) and galvanic couples (including the relative areas of the members of a couple). Accelerated corrosion is not always attributable to these reasons, but these factors are of chief importance, are most readily evaluated, and their effect can be minimized through good design.

One of the first problems to be decided in the design of a system is the selection of piping material. The materials usually considered are steel or wrought iron (both usually galvanized), copper (sometimes coated with a lead-tin alloy by dipping or wiping), red brass, and the copper-nickel alloys. These materials have different corroding characteristics in salt water.

Corroding Characteristics of Galvanized Steel or Iron In Salt Water

The corrosion rate of mild steel in clean, quiescent sea water at normal temperature is approximately 0.005 inch per year. However, due to some tendency towards pitting and to the greater corroding powers of waters



SALT WATER CORROSION OF SHIPS

Figure 5-Leading edge of a bilge keel, showing damage caused by erosion. Note that some rivet heads are also eroded.

in certain localities, it is common practice to assume a rate of 0.010 inch per year for design purposes. The usual galvanized coating of approximately two ounces of zinc per square foot of steel will last about two years under the above conditions, but under flowing water conditions, as in piping, it is assumed to be good for approximately one year. The corrosion of steel may be accelerated by all of the factors pre-

viously mentioned, the most insidious of which are galvanic troubles, because steel is anodic to most other materials used in machinery installations. For example, if a specimen of steel is galvanically coupled to a copper alloy specimen of the same surface area, the normal corrosion rate of the steel will be approximately doubled. Furthermore, the corrosion rate will become proportionately greater as the area of the

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copper alloy member is increased. Hence, one of the essential points which must be borne in mind in the design of a steel piping system is to avoid contact with more noble metals wherever possible.

SALT WATER CORROSION OF SHIPS

When couples can not be avoided, their damaging effect can be minimized by keeping the effective area of the nonferrous member relatively small, by increasing the electrical resistance of the circuit, or by confining the area of rapid attack to a readily replaceable, short section of pipe customarily called a "waster spool."

The velocity of the water has a significant bearing on the corrosion rate, as will be seen in the graph,

Figure 7. These tests were made by pumping Fore River, Massachusetts, sea water through pipes of varying diameters for a period of 36 days. The temperature range of the water was 65 to 80° F. A velocity of 8 to 10 feet per second, which may occur in marine installations, will more than triple the normal corrosion rate of the steel. This factor is difficult to control through design since a reduction in velocity for a given quantity of water can be brought about only by an increase in pipe size and. therefore, in weight, which is undesirable. However, it is important to design a system in such a way that velocities in excess of those designed for, will not occur through mal-oper-

> ation or other channels, and cause unexpected increases in corrosion rate.

> Water temperature must also be considered in predicting the corrosion rate of steel, because the normal corrosion rate doubles with approximately a 50° F. increase in temperature. The use of steel for salt water service at temperatures above 110° F. is not recommended, particularly under flowing conditions.

> The corrosion products of steel are quite voluminous and, in addition, the material is readily fouled by marine growths. For this

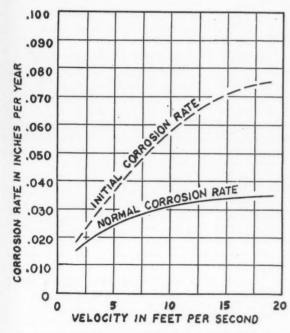


Figure 7—Effect of velocity of salt water on corrosion rate of steel.

reason it is not usual practice to use this material in small diameter lines, say below one inch. It is also good practice to provide for cleaning or steaming out the larger sizes.

Summarizing the characteristics of steel, it has a relatively high normal corrosion rate, which may be increased several times by the recognized accelerating factors. However, it is the least expensive of the commonly used materials and has proved entirely adequate for many services when the accelerating factors have been minimized. Through proper evaluation of these factors, the life of a steel system may be closely predicted, and corrosion failures of mysterious origin are rare.

Copper for Salt Water Piping

Copper, despite its greater cost, has had widespread usage for salt water service, primarily because of its natural resistance to salt water attack under normal exposure and no doubt to its ability to resist fouling. Experience has shown, however, that copper has limitations which curtail its use, the principal one of which is its susceptibility to accelerated corrosion when subjected to high velocities and impingement attack, particularly in the presence of entangled or entrained air. Figure 8 illustrates a typical failure. Copper is also susceptible under stagnant flow conditions to localized attack or pitting. This attack, which in many cases results in perforation, arises as the result of the action of concentration cells.

The variable behavior of copper, which has been experienced in service, does not seem to be controlled by velocity alone, however, and the complementary conditions which lead to rapid failure have not been adequately determined. This material is usually considered to have relatively poor resistance to velocities over five feet per second, but it does not always fail rapidly at higher velocities. Tests similar to those reported for steel in Figure 7 were made on copper tubing at velocities as high as 20 feet per second without evidence of accelerated attack. either with or without entrained air. In these tests, the water was recirculated through the piping and the system was drained and supplied with new salt water every other day. While it may be true that this recirculated water lost some of its corroding power, it was, nevertheless, sufficiently active to give good correlation between corrosion and velocity in the steel piping tests.

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Vol. 4

Variable Velocities and Copper

There is a good possibility that the unpredictable performance of copper may be tied in with a question of variable velocities from point to point, possibly with an accompanying impingement effect, particularly from the point of view of direction or angle of attack. Thus, while copper is likely to fail at velocities above five feet per second and is condemned by the materials or corrosion engineer as a "temperamental" material, it performs in an acceptable manner just frequently enough that owners and designers continue to specify it in lieu of the more expensive copper-nickel alloys which are relatively free of these difficulties.

It is of interest that these undesirable characteristics can be essentially nullified by the application of "tin-wiped" coatings. For those not acquainted with the term, this process consists of applying by a handwiping operation approximately a one-sixteenth inch coating of lead-tin solder, customarily in the order of 60 parts lead to 40 parts tin.

Briefly, the operation is as follows: Copper pipe or tubing, previously pickled to assure clean surfaces, is heated by torch from the outside, fluxed with tallow, and lead-tin solder in stick form melted onto the inner surface. The deposited solder is then manually spread out as uniformly as possible to the desired thickness by use of applicators of tallow saturated felt, "Wiping" describes this levelling process. This lead-tin coating shows very good resistance both to velocity effects (at low to moderate velocities, however), and impingement attack, and likewise to localized corrosive activity under stagnant conditions. One limitation bears mention: Because of the method of application, this process is applicable only to relatively short lengths of fairly large sized pipes (ID of five inches has been set as the minimum size which permits proper application of such coatings).

It should be noted at this point that "tin-dipped" coatings, which might be expected to impart the same favorable properties as do tinwiped coatings, fail dismally. Because of the thin coating which is formed by this method, small areas of base metal, as well as the coppertin-lead alloy which is formed at the interface, are exposed to the salt water, resulting in accelerated pitting of the copper, because it is anodic to the copper-tin-lead alloy and perhaps also to films that develop on the lead-tin alloy surface. Figure 9 illustrates the type of failure that may occur in copper piping coated in this manner. This is likewise shown in Table I, which records the actual corrosion data determined by exposure of these materials to sea water at the Kure Beach corrosion

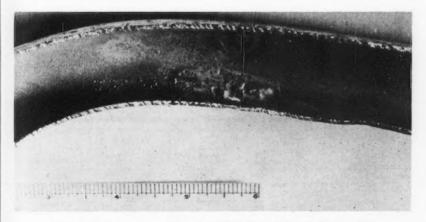


Figure 8-Failure in copper tubing attributable to unsatisfactory flow condition.

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site. It will be noted that the pitting of the tin-dipped specimen is about five times as deep as that of the plain copper specimen.

In way of summary, it can be stated that copper has a good natural resistance to sea water, but is limited in use as a piping material because of its susceptibility to accelerated corrosion under conditions of stagnant flow and moderate to high velocities.

Despite the fact that tin-wiped coatings greatly improve its performance, tin-wiped copper falls far short of a recommended salt water piping material for several reasons, 1) it is costly, 2), it is susceptible to accelerated corrosion at moderate to high velocities and 3), its use is restricted to pipes of short length and large diameter.

Red Brass for Salt Water Piping

The performance of red brass closely approximates that of copper. It has a good natural resistance to sea water, but its use as a piping material is restricted, as is that of copper, because of its susceptibility to accelerated corrosion when subjected to stagnant sea water and likewise to high velocities and impingement attack. Despite these limitations, red brass is used to some

extent, particularly for small sized piping (below one inch) in a system which is otherwise of steel. However, in some of the ships built during the war, where steel was used for large-sized lines as a conservation measure, the lines which caused the most difficulty were the small sized, red brass lines.

Copper-Nickel Alloys for Salt Water Piping

The copper-nickel alloys are outstanding in their resistance to salt water corrosion and to impingement attack. They are not immune to the latter, however, although the level of resistance is considerably higher than that of copper, and a considerable amount of research has been expended toward the improvement of this characteristic. Iron and aluminum additions have been found to produce a remarkable increase in resistance to impingement and to erosion at high velocities.¹

The principal deterrent to the widespread use of these alloys has been the cost. The most favored composition of the group is the 70 percent copper-30 percent nickel alloy with added iron, which offers the best all-around resistance to salt water attack, but the high nickel content makes its use prohibitive in

TABLE I
Corrosion Performance of Coated and Uncoated Copper Subjected to Sea Water Immersion

	Days Exposure	Corrosion Rate I.P.Y.	PITT		
			Maximum	Ave. 10 Deepest	Edges
Copper	776	0.0012	0.027	0.017	Slight Attack
Tin-Wiped Copper	776	0.003	None	None	Unattacked
Tin-Dipped Copper	776	0.0018	0.130	0.094	Attacked

Tests made at Kure Beach, corrosion site of the International Nickel Co., Inc.

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some cases since this alloy costs, approximately twice as much as copper. Preliminary tests on an allov containing only 10 percent nickel and 1 percent iron indicate that it will have a general resistance superior to the 70-30 copper alloy without iron additions, and to all of the usual copper allovs. The low nickel addition makes this

alloy more competitive in a costwise sense. At the present time, it is somewhat more costly than tindipped copper tubing and considerably less costly than tin-wiped copper.

Control of Accelerating Factors in Design of Salt Water Systems

Galvanic couples between dissimilar metals are the most amenable to control of all the corrosion accelerating factors and premature failures due to this type of attack should not occur in a modern piping system. When dissimilar metals must be coupled, it is important to keep in mind not only their relative positions in the galvanic series of metals, but also the relative areas of these metals. When the area of the more noble metal is relatively small. the couple may be frequently made without an excessive increase in corrosion rate, but when the area is nearly equal to, or greater than the area of the less noble metal, the latter will be corroded rapidly. For this reason, threaded joints between dissimilar metals should always be



Figure 9—Type of failure which may occur in copper tubing with inadequate coating of tin-lead alloy produced by dipping.

avoided. The effective areas of the coupled metals in this type of joint are, for all practical purposes, equal, and the individual thread thicknesses are small as compared with the pipe wall thickness, so that premature failure is certain to occur. The preferred method is to braze the joint, thus excluding water and preventing the unfavorable galvanic arrangement.

A likely source of trouble in a steel piping system is encountered when small sized branch lines are made of red brass or other nonferrous metals. If the reduction of size is made in the branch fitting or tee. the area of the nonferrous piping will be approximately equal to the area of that leg of the fitting which is exposed to the galvanic couple, and the corrosion rate in the fitting will be high. However, if the size reduction is made not in the fitting but by means of a special flange attached to the nonferrous piping, the galvanic couple may be brought under control. This can best be seen by Figure 10. If the diameter of the

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steel branch fitting is at least twice that of the nonferrous piping, the increased corrosion rate attributable to the galvanic couple will not be excessive. If the size ratio is less than two, the fitting and the main line may be protected by interposing a short length of heavy walled steel pipe between the fitting and the branch line to act as a waster

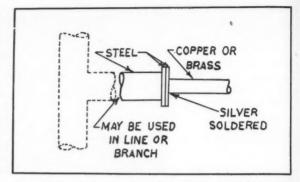


Figure 10—Preferred method for joining nonferrous material to steel in a salt water piping system. Note that area of steel exposed is kept large as compared with that of copper. Where diameter of steel pipe or branch is less than twice that of copper, an easily replaceable section of steel pipe should be incorporated, to act as a washer.

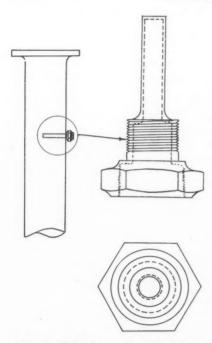


Figure 11—Typical thermometer well used in marine installations. Note large difference in area between stem of thermometer well and surrounding surface of piping.

piece. Thus the area of accelerated corrosion is confined to a readily replaceable member, the life of which is determined by its wall thickness.

Galvanic corrosion may also be minimized or eliminated by increasing the electrical resistance of the circuit, since the corrosion process depends directly upon the flow of current. Thus, if a bronze valve body were placed in a steel line, galvanic corrosion could be prevented by electrically insulating the valve from the steel piping and from the hull of the ship (the external circuit of the cell). However, adequate insulation is diffcult to obtain and a more dependable solution of the problem would be to place rubber-lined insulating spools on either side of the valve, thus increasing the resistance of the circuit by separating the members of the cell. A situation of this sort is not unusual, because smaller sizes of valves are frequently made only in bronze and the preferred steel valve bodies are not stocked.

Galvanic corrosion in copper or

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copper-nickel alloy piping is seldom encountered, because couples with large areas of more noble metals are unusual. However, care must be used in the design of small-sized attachments to the piping, because they will be attacked if less noble than the piping. When the difference in areas is great, even metals within the same galvanic group may be severely corroded. A good example of this is the case of the thermometer wells, shown in Figure 11. These fittings were formerly made of naval brass and screwed into tinned copper piping with good results in service. In one of the early copper-nickel alloy piping installations, it was found that naval brass

was no longer suitable for thermom-

SALT WATER CORROSION OF SHIPS

eter wells since the galvanic attack corroded them through in approximately six weeks' time, as shown in Figure 12. Small attachments of this type must be more noble than the piping, and in this case the naval brass was successfully replaced with Monel.

Velocity of water flow is a significant factor in the corrosion of all of the piping materials. These materials apparently depend, for their resistance to corrosion, upon the formation of a surface film of corrosion products which tends, in vary-

ing degrees, to stifle further corrosion. When the water velocity in a given material exceeds a critical amount, the protecting film is washed away and corrosion is allowed to progress at the high initial rate. This accelerating factor can be controlled in design by providing pipes of sufficient size to maintain a velocity within the limits of the material involved, due consideration being given to actual pump capacities rather than rated capacities and to the prevention of excessive velocities through mal-operation. In those locations where control of velocity is not practicable, a material which is resistant to the highest expected velocity should be used.

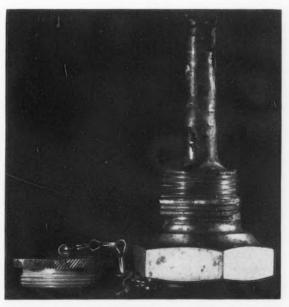


Figure 12-Naval brass thermometer well removed from service in cupro-nickel piping after a six-week period.

Impingement attack is controlled to some extent by the "streamlining" of the piping interior, wherever possible, to eliminate unnecessary turbulence in the water. Turbulence cannot be completely eliminated, however, and since copper is particularly susceptible to this form of attack, failures in this material are not uncommon.

Failures of this type are particularly disconcerting, as they are evidenced by a rapid penetration of the pipe wall, sometimes after a period of operation measured in minutes, or a few hours. The alloys of copper, nickel, and iron previously mentioned show good resistance to this form of attack, and piping systems of these materials operated under moderate conditions of turbulence are not expected to fail.

Auxiliary Equipment

The foregoing principles, which have been discussed primarily in relation to piping, may also be applied to other items of marine machinery equipment such as valves and heat exchangers. The range here of applicable materials is likely to be considerably wider than for piping since mechanical properties frequently are equally as important as corrosion resistance. Thus, we find rolled products such as Monel, stainless steel, brass, or steel, and cast products such as gun metal, valve bronze, silicon monel, and cast iron, or steel entering into the construction of marine machinery. Years of experience with these standard items of auxiliary equipment have led to the establishment of satisfactory combinations of these various materials. However, during the recent war, when metals of all

types were scarce, some ill-advised substitutions in the accepted lineup of materials were made. It was necessary to re-emphasize that an anodic material must never be made the smaller member of a galvanic combination. As an illustration, the preferred material for valve stems in salt water service is Monel. Due to the wartime scarcity of Monel, many other materials were considered for this service, including manganese bronze, naval brass, and 13 percent chromium stainless steel. some people failed to realize was that while these substitutions might provide acceptable service in a steel valve body where they would receive galvanic protection, they would be totally inadequate in a bronze body where they would be surrounded by a relatively large area of cathodic material. Thus, changes in the accepted combinations of materials can be made satisfactorily only after a careful study of all the materials and conditions involved.

Condenser Tubes

No article of this type would be complete without mention of marine condenser tube corrosion which, in the past, presented serious troubles and which, even today crops up on occasion. Many papers on this subject have been published of which those of Bengough³ and May⁴ undoubtedly are best known. As a result of their work and that of others in the field, condenser design and materials have been altered to the extent that corrosion troubles have been materially reduced.

The principle design changes have been directed toward the improvede:
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ment of water flow into the condenser tubes by the elimination of conditions causing turbulence. This is accomplished by streamlining the piping system which supplies the condenser, increasing the depth of the condenser head or water box, belling the tube ends and grinding them flush with the tube sheet, recessing any zinc or iron waster pieces which may be specified, and by maintaining a relatively low water velocity in the tubes.

The use of cupro-nickel and aluminum brass in lieu of admiralty brass for tubing has been the outstanding change in materials used in condenser construction. Another significant change being adopted with increasing frequency is the elimination of cast iron heads in favor of a material which is galvanically compatible with the tube sheet material.

The above changes have been effective to the extent that, in our experience at the time of writing, condenser corrosion is no longer a serious problem. While some difficulties may arise, they are of a minor nature and are readily repairable.

Summary

The fundamental principles governing marine corrosion processes

are well enough understood that they can, in most cases, be controlled. A somewhat wider dissemination of these principles might be helpful, however, in avoiding unsatisfactory details of construction which may result inadvertently during design or fabrication of a system.

One of the biggest gaps in our knowledge at the present time concerns the inconsistent behavior of copper (both plain and tin-dipped) in piping systems. The factors which must accompany high velocity in the production of rapid failures are not well understood. Until these factors are determined, reliable performance of copper as salt water piping cannot be expected, nor can a completely satisfactory explanation of the failures. The only alternatives at present are the use of steel which is less expensive and of a relatively short, but predictable life, or the use of a longer lived, but a more expensive alloyed material, such as cupro-nickel. The latter solution has not as vet gained wide acceptance in merchant shipbuilding because of the occasionally satisfactory behavior of copper coupled with the appreciably higher cost of the cupronickel alloys as compared with the initial cost of plain copper.

References

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- Paul Field, Recommendations for Using Steel Piping in Salt Water Systems, J. Am. Soc. Naval Engrs., 57, 1-20 (1945) Feb.
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- R. May, Condenser Tube Corrosion; Some Trends of Recent Research, Trans. Inst. Marine Engrs., 49, 171-176 (1937).

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President F. L. LaQue

N. A. C. E. Officers for 1948-49

and

New Members of the Board of Directors

D. E. STEARNS

V. N. JENKINS

L. J. GORMAN







Conference Attendance Reflects Growth Of NACE During Past Year

CTRIKING power of the National Association of Corrosion Engineers-this Country's biggest task force in the War on Waste, from the standpoint of metal losses attributable to corrosion, was demonstrated April 5-8, 1948, during the Association's Conference and Exhibition, held at the Hotel Jefferson in St. Louis, Mo. More than 1200 persons (853 of whom were registered members of the Association) gathered in St. Louis to discuss and devise ways and means for continued attack upon the great destroyercorrosion.

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That creation of NACE constituted a great public service by virtue of the diversity of its attack upon corrosion is evidenced by the great savings in natural resources, and management's realization that through cooperation - inter-industrial cooperation—avoidance of duplication of effort, and the correlating and dissemination of corrosion data have resulted in increased metal life, fewer shutdowns, reduced operational costs, and better public relations through avoidance of service interruptions and a higher quality product at less cost for the user and consumer.

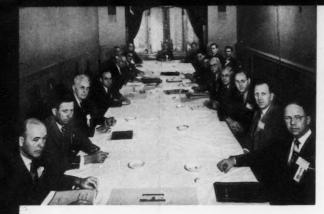
Though metal losses have been greatly reduced since the attack against this industrial enemy was launched by the pioneer force in 1943, the technical papers—41 being

presented during the ten symposia—revealed new advances in the science of corrosion control, and detailed information for better utilization of presently available weapons. And 53 exhibitors displayed the weapons presently available.

The various symposia each attracted an average of 325 listeners, with many sessions presented before overflow audiences. Interesting and illuminating discussions followed the presentation of each paper. Of particular interest were those papers on the phenomena of blistering, one of which is presented in this issue of



A. B. CAMPBELL Re-elected Executive Secretary



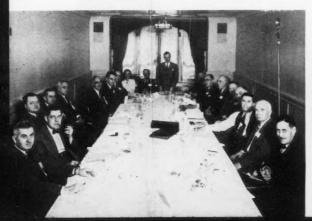
BOARD OF DIRECTORS—From left: W. Rogers, T. L. Holcombe, L. J. Gorman, O. C. Mudd, A. B. Campbell, G. R. Olson, J. T. MacKenzie, J. M. Pearson, F. L. LaQue (Chairman), V. N. Jenkins, P. W. Bachman, M. G. Fontana, M. H. Jackson (Visitor), Ivy M. Parker, H. M. Trueblood, R. B. Mears, H. J. McDonald, F. L. Goldsby, D. E. Stearns.

CORROSION, starting on Page 187. Also of interest was that the tests conducted by the Condensate Well Committee revealed 9 percent chrome and 9 percent nickel steels as the most economical and feasible for application in condensate well service: The interesting point being that such a steel was the outgrowth of investigations carried on by corrosion engineers, and not the result of research by the steel industry. Normally the reverse is true. The 9 percent nickel is now in mass production for tubing.

The great influx of early arrivals caused officials to open the registration desk Sunday, a day ahead of schedule. Registrations mounted rapidly, exceeding at 9 A. M., Tuesday morning the number of registrations for the 1947 conference, held in Chicago. St. Louis was a busy place,

all hotels reporting all reservations taken. Many members were housed privately. The meeting attracted visitors from every section of the country, and included several from Canada and Mexico.

The Conference and Exhibition opened officially Monday with registration in the morning and the General Assembly in the afternoon. G. R. Olson, United Gas Pipe Line Company, Shreveport, La., presided over the General Assembly, during which J. C. Stirling, Stanolind Pipe Line Co., Tulsa, Okla., and J. W. McAfee, President of Union Electric Co. of Missouri, were guest speakers. The business meeting, during which various technical committee chairmen reported, as well as the president, treasurer and executive secretary, was presided over by F. L. LaQue, The International



AMERICAN COORDINATING COM-MITTEE ON CORROSION—From left: F. L. LaQue, L. H. Enslow, R. F. Hadley, A. V. Smith, J. T. MacKenzie, R. B. Mears, H. T. Francis, H. J. McDonald, (Unknown Recorder), K. H. Logan, G. W. Seagren (Chairman), G. H. Young, Sam Tour, F. N. Speller, R. Pope, C. Fellows, M. G. Fontana, C. Upthegrove, and J. G. Thompson. Outgoing President, G. R. Olson, addresses General Assembly. From left: F. L. Goldsby, General Conference Chairman; Mr. Olson, J. W. McAfee, guest speaker; Incoming President, F. L. LaQue, and Treasurer O. C. Mudd.



Nickel Co., New York, Vice-President and President elected for 1948-49.

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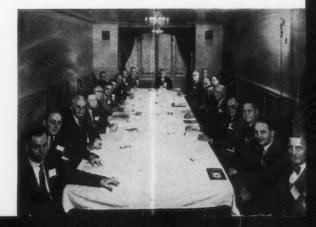
Upwards of 450 persons jammed the Gold Room—largest dining room in the hotel—for the annual banquet. Many persons were turned away because the Hotel did not have facilities for handling the record gathering. The banquet was highlighted by introduction of officers, presentation of NACE awards in the field of corrosion, and an address by Miss Beulah Schacht, of the St. Louis Globe-Democrat.

Mr. Olson, retiring president, in-

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Another highlight of the banquet

COMMITTEE ON RELATIONS
WITH OTHER TECHNICAL SOCIETIES—From left: H. J. Butterill, H. J. McDonald, L. T.
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Tour, H. P. Godard, M. G. Fontana, F. A. Rohrman, L. H. Enslow, A. W. Tracy, J. T. MacKenzie, F. L. LaQue (Chairman), G.
C. Cox, H. T. Kennedy, R. F.
Hadley, R. B. Mears, A. V. Smith,
F. N. Speller, C. H. Fellows, H.
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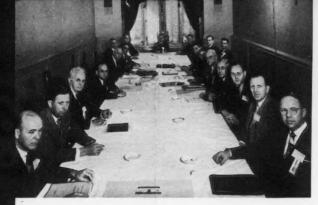
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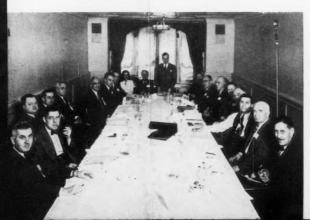
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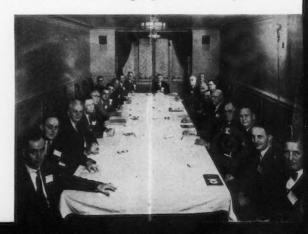
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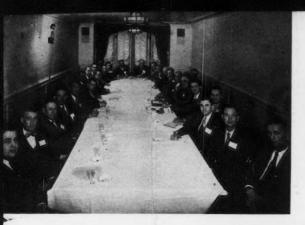
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MEMBERSHIP CONTROL COMMITTEE—From left: C. B. Lester, H. H. Febrey, L. F. Greve, W. C. Honecker, Chris A. Goldkamp, C. R. Davis, E. D. McCauley, E. C. Gosnell, D. J. Connelly, E. W. Vereeke, D. A. Scanlon, J. Pat Casey, Jr., S. D. Day, T. L. Holcombe, H. H. Anderson (Chairman), W. A. Broome, Nathan Shofer, W. G. Horstman, H. A. Robinson, I. C. Dietze, H. C. Van Nouhuys, C. H. Fellows, R. B. Hoxeng, D. B. Good, W. P. Noser, R. L. Bullock and W. H. Stewart.

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Rogers, G. Heinemann, V. V.
Kendall, T. L. Holcombe, F. L.
LaQue, R. B. Mears (Chairman), M. A. Scheil.

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O. L. Jensen, K. S. Hagius, F. B.
Fry, O. C. Roddey, L. R. Sheppard,
W. P. Noser, I. B. Tietze, M. C.
Fleming, L. B. Nelson, L. E. Nichols,
P. E. Busch, G. L. Doremus, G. A.
Mills, S. J. Artese, R. F. Maurer,
G. D. Harden, E. L. Karraker, E. H.
Rush, H. A. Humble, F. N. Speller,

O. Osborn, A. Smith, Jr., D. B. Good, R. L. Bullock, J. M. Pearson, K. L. Weaver, G. C. Cox, Col. J. A. Davenport, R. H. Brown, K. K. Reid, H. V. Beezley, M. E. Parker, Jr., C. B. Abbott, M. C. Miller, E. H. Thalmann, C. R. Draughon, D. J. Fergus, A. S. Munneke, Lee N. Spinks, V. J. Sittel, H. M. Fanett, H. W. Wahlquist, N. Schofer, Ed Doremus, J. A. Holloway.

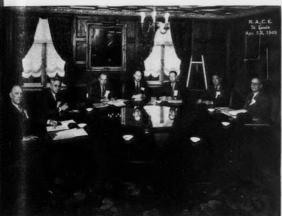
CONDENSATE WELL COR ION (left: Jack L. Battle, H. A. H. ble, C. Carter, E. H. Sullivan, H. T. Giffin, R. Zajac, D. T. MacRoberts, Y. V. Kenn (Chairman), P. D. Thoms, H. M. Co. John Juppenlatz, C. Kenneth Eilerts, B. B. Morton, H. T. Kennedy, (





COMMITTEE ON CORROSION PROBLEMS INVOLVED IN PROCESSING AND HANDLING CHEMICALS—Present: John J. Halbig, W. Luce, E. C. Reichard, J. T. Thornberg, G. C. Kiefer, C. R. Ahlgren, E. G. Holmberg, C. I. Wright, E. W. Segebrecht, A. C. Goetz, J. Pat Casey, Jr., G. Heinemann, Paul J. Gegner, W. Z. Friend, C. F. Pogacar, A. Wachter, L. D. Cook, Jr., J. T. Robbins, J. F. Mason, Jr., Frank L. Whitney, Jr., S. J. Artese, C. Max Widmer, C. L. Clark, P. H. Smith, L. G. Vande Bogart, F. A. Rohrman, E. D. Verink, M. A. Scheil, and M. G. Fontana (Chairman).





REGIONAL MANAGEMENT COMMITTEE—From left: E. P. Noppel, James T. MacKenzie, G. B. McComb (Chairman), Hugh J. McDonald, F. J. Mc-Elhatton, Vance N. Jenkins, H. M. Trueblood.

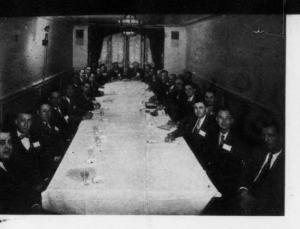
PROTECTIVE COATINGS COM-MITTEE—Present: T. L. Holcombe (Chairman), D. L. Korn, R. E. Clark, P. H. Miller, F. Ringer, G. Diehlman, A. C. Goetz, O. C. Roddey, W. Beck, J. J. Halbig, F. A. Hunold, R. A. Shoan, A. L. Stegper, T. H. Gilbert, J. A. Davenport, L. R. Sheppard, A. S. Munneke, R. V. Richardson, J. N. Hunter, Jr., M. Savoy, E. W. Segebrecht, H. P. Griggs, A. W. Peabody, F. D. Stull, D. Holsteyn, C. K. John-

F. D. Stull, D. Holsteyn, C. K. Johnson, T. B. McDonald, H. V. Breezley, R. F. Maurer, P. S. O'Brien, W. A. Broome, W. S. Bradford, I. B. Tietze, B. L. Corey, W. B. Haas, H. F. Haase, W. T. Pyott, J. H. Gillard, L. B. Nelson, V. N. Jenkins, T. J. Maitland, D. H. Marlin, E. G. Holm, C. C. Harvey, B. Patterson, E. G. Johannes, M. L. Rosenberg, H. M. Trueblood, K. G. Compton, O. L. Jensen, R. A. Brannon.









MEMBERSHIP CONTROL COMMITTEE—From left: C. B. Lester, H. H. Febrey, L. F. Greve, W. C. Honecker, Chris A. Goldkamp, C. R. Davis, E. D. McCauley, E. C. Gosnell, D. J. Connelly, E. W. Vereeke, D. A. Scanlon, J. Pat Casey, Jr., S. D. Day, T. L. Holcombe, H. H. Anderson (Chairman), W. A. Broome, Nathan Shofer, W. G. Horstman, H. A. Robinson, I. C. Dietze, H. C. Van Nouhuys, C. H. Fellows, R. B. Hoxeng, D. B. Good, W. P. Noser, R. L. Bullock and W. H. Stewart.

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TECHNICAL PRACTICES
COMMITTEE—From left: M.
G. Fontana, J. M. Pearson, W.
Rogers, G. Heinemann, V. V.
Kendall, T. L. Holcombe, F. L.
LaQue, R. B. Mears (Chairman), M. A. Scheil.

GALVANIC ANODE COMMITTEE
—Present: T. B. McDonald, C. R.
Davis, K. H. Logan, N. P. Peifer,
O. L. Jensen, K. S. Hagius, F. B.
Fry, O. C. Roddey, L. R. Sheppard,
W. P. Noser, I. B. Tietze, M. C.
Fleming, L. B. Nelson, L. E. Nichols,
P. E. Busch, G. L. Doremus, G. A.
Mills, S. J. Artese, R. F. Maurer,
G. D. Hardén, E. L. Karraker, E. H.
Rush, H. A. Humble, F. N. Speller,

O. Osborn, A. Smith, Jr., D. B. Good, R. L. Bullock, J. M. Pearson, K. L. Weaver, G. C. Cox, Col. J. A. Davenport, R. H. Brown, K. K. Reid, H. V. Beezley, M. E. Parker, Jr., C. B. Abbott, M. C. Miller, E. H. Thalmann, C. R. Draughon, D. J. Fergus, A. S. Munneke, Lee N. Spinks, V. J. Sittel, H. M. Fanett, H. W. Wahlquist, N. Schofer, Ed Doremus, J. A. Holloway.

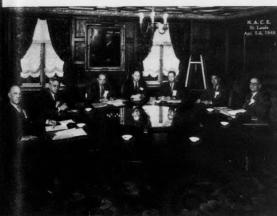
CONDENSATE WELL CORR SION C left: Jack L. Battle, H. A. Humble, C. Carter, E. H. Sullivan, H. T. Griffin, R. Zajac, D. T. MacRoberts, V. V. Kend (Chairman), P. D. Thomas, H. M. Coo John Juppenlatz, C. Kenneth Eilerts, B. B. Morton, H. T. Knnedy, C





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CORR SION COMMITTEE—From A. Himble, C. E. Farmer, Ben F. H. T. Iriffin, R. S. Treseder, T. S. rts, V. V. Kendall, W. F. Rogers nas, H. M. Cooley, F. A. Prange, enneth Ellerts, Francis G. Archer, I. T. Knnedy, O. E. Berg. PROTECTIVE COATINGS COM-MITTEE—Present: T. L. Holcombe (Chairman), D. L. Korn, R. E. Clark, P. H. Miller, F. Ringer, G. Diehlman, A. C. Goetz, O. C. Roddey, W. Beck, J. J. Halbig, F. A. Hunold, R. A. Shoan, A. L. Stegner, T. H. Gilbert, J. A. Davenport, L. R. Sheppard, A. S. Munneke, R. V. Richardson, J. N. Hunter, Jr., M. Savoy, E. W. Segebrecht, H. P. Griggs, A. W. Peabody, F. D. Stull D. Holsteyn, C. K. John-

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Annual Banquet

Conference Scenes

General Assembly



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roupeduce n in roble rgan or c JBLICATION COMMITTEE—From ft: Lorraine R. Voigt, Ivy M. Parker, hairman and Editor of CORRO-ON; W. M. Wernett, Managing itor of CORROSION; L. G. Vande Bogart, and E. R. Stauffacher.



as presentation of the NACE wards in the field of corrosion by N. Speller, chairman of the NACE wards Committee. This year, Mr. earson was presented the Frank ewman Speller Award in Corroon Engineering, and Ulick R. vans, Cambridge University, Engnd, received the Willis Rodney Whitney Award in the Science of forrosion. Mr. Pearson was present b receive his award, but Mr. Evans as forced to forego that pleasure. n his absence, R. B. Mears, Caregie-Illinois Steel Corp., accepted he award for transmittal to the onoree.

ndependent Corrosion Group Now NACE Affiliate

Arrangements were completed uring the meeting for the consoliation of the activities of the Ameran Coordinating Committee on orrosion with the NACE Committee on Relations with Other Technial Societies. This was the outgrowth in invitation extended to the roup, as an effort to bring about a eduction in duplication of work, and increased concentration upon roblems of corrosion. Sponsoring ganizations accepted the invitation or consolidation, with the result

that ACCC was dissolved as an independently operating group sponsored by a number of societies. Its activities will be continued under the sponsorship and direction of NACE.

An aside from the technical aspects of the show were the many "Open House Cocktail Hours" sponsored by manufacturers and exhibitors. The scheduled Cocktail Hour started festivities Monday evening, with another "spur of the moment" cocktail hour on Tuesday evening. Many exhibitors had "open house" in their suites. There was also an unscheduled piano "Jam Session" Thursday afternoon, with Bill Huddleston, of the Huddleston Engineering Co., leading the "Symposia Boogie Session," an impromptu session held in the transportation storage room on the exhibition floor.

Encouraged by the results of the 1948 Conference and Exhibition, officials immediately launched plans for a "bigger and better" All-Corrosion Show for 1949. It was announced that next year's conference will be held at the Netherland Plaza Hotel, Cincinnati, Ohio. Tentative dates are April 11 to 14.

NACE Awards 9

Willis Rodney Whitney Award in the Science of Corrosion

Presented to

DR. ULICK R. EVANS

ULICK R. EVANS was born March 31, 1889, at Wimbledon, England, and was educated at Marlborough College, 1902-1907 and in King's College, Cambridge, 1907-1911. He received a B.A. in 1910, M.A. in 1914 and Sc.D. in 1932; all from Cambridge University. Immediately after obtaining his M.A., World War I started and he was in the Army from 1914 to 1919. Since then, he has been engaged continuously at scientific work at Cambridge University, mainly in studies of corrosion of metals, thin films on metals and recrystallization changes in metallic structures. He has published some 180 papers, either alone or with 27 collaborators.

Besides lecturing at Cambridge University, he has delivered lectures by invitation at many centers in Great Britain, United States, France, Germany and Switzerland. In December, 1947, he was awarded an Honorary Sc.D. Degree at



Dublin University. He is the author of several books, including the four-volume series "Metals and Metallic Compounds' published in 1923; the "Corrosion of Metals" in 1924 and 1926; "Metallic Corrosion, Passativity and Protection" in 1937 and 1946; while now in the press is a new book entitled "An Introduction to Metallic Corrosion." His books have been published not only in English Editions, but also German, French and Russian Editions

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Dr. Evans' interest in corrosion arose during the years he was writing "Metals and Metallic Compounds." At that time, it became evident to him that the reasons for the stability of metals in air, not withstanding the fact that in many cases there was a high affinity for oxygen, were not well understood. It was necessary to ascribe this stability to the formation of protective films, but it was not clear why in certain cases protection failed, so that corrosion proceeded rapidly. It was obvious that much experimental work would be needed before we would begin to understand the principles involved. Since that time, Dr. Evans has been working continuously in this general field. Probably his most important contributions have been his studies on the electrochemical nature of corrosion. In fact, the first quantitative measurements coordinating corrosion rate with the amount of electric current flow-ing during "natural" corrosion were made in his laboratory. His work on thin films, their isolation and measurement, has also

been extremely important.

Because of the extent, accuracy and clear presentation of the results of his work, he has influenced the thinking of other workers in the field of corrosion more than any other person. Many workers engaged in studying the mechanism of corrosion have worked at Cambridge under his guidance and practically all workers in this field have benefitted by

his books and papers.

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Frank Newman Speller Award in Corrosion Engineering

Presented to

DR. JOHN M. PEARSON

JOHN M. PEARSON was born in Portland, Oregon, where he attended Reed College. He completed his undergraduate work at the University of Chicago, receiving a B.S. degree in 1925. His graduate work was done at the California Institute of Technology, where he served as instructor for three years and received a PhD, degree in 1930. While working on his doctorate, he became associated with the Sun Oil Company, Dallas, Texas, working in electrical geophysics. In 1931, he transferred to the Susquehanna Pipe Line Company, an affiliate of Sun Oil, as Physicist becoming, in turn, Chief Engineer and finally Manager of that Company. In 1945, he returned to the Sun Oil Company, and is at present Director of the Sun Physical Research and Development Laboratory.

While with the Susquehanna Pipe Line Company Dr. Pearson was in charge of corrosion work on the Company's properties, particularly its underground pipes. During this time he made many valuable contributions to corrosion engineering of which the following have been selected for mention.

Study of the distribution of current and potential along a structure with cathodic protection and along a paralleling unprotected structure leading to the theory of conjugate anode location to minimize the effect on the unprotected structure.

A method of simulating the effect of an insulating joint in an underground structure for test purposes without the necessity of actually installing such a joint.

The use of network constants in computing the size of drainage wire required in stray current areas and in correlating the practices on the various structures involved.

A method of detecting holidays in pro-

tective coatings on underground structures by applying an audible frequency potential between the structure and earth and surveying the route of the structure with earth potential probes, an amplifier and headphones.

Analysis of local cell action on an underground structure and the develop-ment of a method of determining the cathodic protection current required on the basis of the cell action and the polarization of the structure.

The development of the so-called "null method" of measuring the polarization characteristics of an underground structure by means of a Wheatstone Bridge type of circuit which eliminates the necessity of excavating the structure.

These contributions to corrosion engineering are described in the papers Dr. Pearson has prepared over the years.





NACE News

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GENERAL INTEREST

On June 11 and 12 the seven chapters of the American Society of Metals which are located wholly or partly in Pennsylvania will hold their Sixth Biennial Pennsylvania Interchapter Meeting at State College, Pennsylvania, under the auspices of the Penn State Chapter.

An attractve technical program has been arranged, and will feature an address by M. A. Grossman on "The Toughness and Fracture of Hardened Steels." The session on Friday afternoon, June 11, will be given over to a symposium on notch sensitivity in mild steels. Three papers will be presented by outstanding workers in the field, and there will be ample time for discussion of this important and timely subject. The session on Saturday morning will be of a more general character and will appeal to both ferrous and nonferrous metallurgists.

An informal banquet and entertainment on Friday night will highlight the non-technical part of the program,

The Tulsa Section of the South Central Regional Division of NACE installed new officers at a dinner meeting held in that Oklahoma City on February 19. Officers for 1948 are: Chairman, R. L. Bullock, Interstate Oil Pipe Line Co., Tulsa; Vice-Chairman, I. B. Tietze, Phillips Petroleum Co., Bartlesville; Secretary-Treasurer, F. M. Cloninger, The Texas Pipe Line Co., Tulsa. The next meeting of the Tulsa Section will be held May 20, and will be a joint meeting with the International Petroleum Congress scheduled for that date. G. L. Crain, Interstate Oil Pipe Line Co., Shreveport, La., will present the paper, Installation and Performance of Scale Traps in Sour Crude Service, and Scott P. Ewing will read the paper, Cathodic Protection of Casing in Loudon Pool, which he prepared in collaboration with his fellow worker at The Carter Oil Co., Tulsa, J. F. Bayhi. Mr. Ewing presented the same paper at the National meeting of NACE held April 5-8 in St. Louis.

Over 100 engineers of leading industrial organizations throughout the United States witnessed an unusual test of various metal experimental vessels at liquid nitrogen temperatures of below —300° F., recently staged at the Air Reduction Apparatus Research Laboratory, Murray Hill, N. J. The various metals tested were: 8½% nickel steel, AISI 2800; stainless steel, type 304; and carbon steel, ASTM A201.

The development of 8½% nickel steel has created wide interest among the users of vessels that are required to operate at liquid air temperatures, and although laboratory tests at -320° F. on welded and unwelded specimens indicated a considerable degree of toughness at the temperature of liquid nitrogen, it was decided to build several small vessels and subject them to a test at a temperature of below -300° F.

Results of the test showed no material damage to 8½% nickel steel and stainless steel vessels, while a carbon steel vessel was shattered upon the first impact. The vessels were fabricated from these materials with all major joints being X-rayed for defects, as well as being subjected to a 700-pound hydrostatic test.

The test consisted of dropping a weight on the vessels while filled with liquid hydrogen. For the 8½% nickel steel and stainless steel vessels, a weight of 292.9 pounds was dropped from a height of five feet at the intersections of the longitudinal and transverse seams; at two locations along the longitudinal seam; and on the flange of the nozzle. For the carbon steel vessel, a weight of

184.9 pounds was dropped five feet near the longitudinal seam about midway between one end and the nozzle.

While 8½% nickel steel was commercially developed primarily for engineering structures at low temperatures, it is being found to possess a versatility which fits it for a wide variety of applications at normal temperatures as well.

There are numerous fields for which the alloy is either being considered or is already being used. Limited experience indicates that it probably will find wide use for sucker rods in certain types of corrosive oil wells and for oil well tubing in deep wells. Several trial installations of seamless tubing have been used in black liquor evaporators in the pulp and paper industry.

In connection with corrosion resistance, however, the 81/2% nickel alloy cannot be considered as a substitute for the 18-8 types of chromium-nickel stainless steels. It may be suitable for applications involving a particular type of corrosion. Nor is it suggested as a replacement for the low alloy steels for applications in which high strength is the primary consideration. In certain respects this new nickel steel does have such advantages as combinations of valuable properties with moderate cost. This, beyond a doubt, will ultimately determine its proper position as an engineering material.

While the test was sponsored by the International Nickel Company, Inc., it was conducted by the staff of the Air Reduction Apparatus Research Laboratory, with D. D. Snavely, Junior Engineer, in direct charge of the program.

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The American Electroplaters' Society, through its Research Committee, is engaged in an extensive program of research on the quality of electroplated coating. This research work was started to help industry increase output from existing equipment, reduce the percentage of rejects, and raise the quality of the goods. This program, which includes eight other related projects, is supported by over 200 industrial concerns.

Two research projects deal with impurities in plating baths, some of which have a tremendous effect when present in quantities as small as 1/1000 ounce per gallon. These studies include development of new and rapid methods for the analysis of impurities and methods for removing them from plating solutions. Even though impurities may not affect the appearance of the plated part when it is new, they may well cause rapid tarnishing, rusting or other type of failure. Preliminary results have indicated that the quality of plated products can be greatly improved by good control in the plating plant. The research projects of the American Electroplaters' Society are placed at universities, the National Bureau of Standards and other research institutions. The effects of impurities are being studied at Michigan State College under Professor D. T. Ewing, and analytical methods are being developed at Lehigh University under Professor E. J. Serfass.

Technical sessions on rate metals, fluorescent materials, furnace refractories, corrosion, and electrode proc-

esses featured the Spring Convention of The Electrochemical Society, held in Columbus, Ohio, April 14 to 17. At these sessions more than three dozen research papers were presented by experts in their respective fields.

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In addition to the technical program, a full schedule of luncheon meetings, a buffet supper, plant visitations, and the annual banquet provided opportunities for convening electrochemists to become acquainted socially. On the distaff side, was a complete program for the ladies, including a luncheon and a guided tour through a glass plant.

Headquarters for the Convention was the Deshler-Wallick Hotel in Columbus.

The firm of Sam Tour & Co. Inc., engineers, metallurgists, consultants, is expanding its laboratories and workshops to better handle the increase in the volume of its business. Two and one-half floors of additional space, in its building at 44 Trinity Place in downtown New York, are being taken over a tenants vacate. When the transition is completed, seven floors of this building will be occupied completely by the organization.

Proved natural gas reserves in the United States on December 31, 1943, were 165.93 trillion cubic feet and proved liquid hydrocarbon reserve were 24,741,660,000 barrels, it was estimated last month in a joint report of the committee on reserves of the American Gas Association and the American Petroleum Institute.

Personals

E. J. McMahon, Production Manager of the Dearborn Chemical Company, was elected a Director and Vice-President at the annual stockholders' meeting held at the company's main offices, 310 South Michigan Avenue, Chicago. He succeeds John W. Brashears, who has been with Dearborn Chemical Company 52 years, a member of the Board of Directors since 1912, and who was retired as an honorary director for life.

W. E. Quillian has been appointed Chief Estimator and Purchasing Agent of the Salem Engineering Company's South West Branch at Fort Worth, Texas. A graduate of Georgia School of Technology, Mr. Quillian joined the Salem Engineering Company as an erection engineer and served in this capacity until 1942, when he entered the armed forces. Released in 1946, he returned to the Salem Engineering Company's main office at Salem, Ohio. Until his recent appointment to the South West Branch, Mr. Quillian served as Chief Estimator in the Company's main office.

Appointment of James A. McRae of Houston, Texas, as "Coro-Gard" sales engineer has been announced by the adhesives and coatings division of Minnesota Mining and Manufacturing Co., St. Paul, Minn. McRae, introducing the firm's anti-corrosion coating for oil tank interiors, will concentrate his attention in the Midland-Odessa fields. McRae, 28,

a Marine Corps veteran, first worked in the oil fields summers as a roughneck, while attending Southern Methodist University at Dallas. Postwar, he worked two years as a bidder and estimator on oil field contracting and construction.

Marshall Parker has joined the staff of the Cathodic Protection Service, Houston, Texas. Mr. Parker was formerly associated with Pan American Pipe Line Co. as a corrosion engineer.

A. E. M. Shafer, Research Engineer, Pennsylvania Power & Light Co., died suddenly April 5 at his Allentown, Pa., home Mr. Shafer was 50 years old. A graduate of Lehigh University, he was recognized as one of the outstanding engineers in the Lehigh Valley. Mr. Shafer had always been active in engineering society affairs and in the associations of the electric, gas and steam heat utility industries. He was a member of the National Association of Corrosion Engineers, the American Society of Mechanical Engineers, the Engineers Club of Lehigh Valley, both the Pennsylvania and National Societies of Professional Engineers, the Pennsylvania Electric Association and the National District Heating Association. At the time of his death he was active in the Prime Movers Committee of the National District Heating Association.

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NEW PRODUCTS, MATERIALS AND SERVICES

A multi-combination meter, designed specifically for electrolysis and corrosion investigations and cathodic protection testing both in field and laboratory has been developed and is now available. It provides all of the instrumentation required to cover the wide range of d-c current and potential measurements necessary in this field. By use of a circuit selector switch, a highsensitivity, 300 ohms-per-volt millivolt/voltmeter covering ranges of 2 millivolts to 100 volts, full scale, and a high-sensitivity, 62,500 ohms-pervolt voltmeter with ranges of 100 millivolts to 20 volts full scale, are provided. Either may be used separately, or simultaneously. Also provided are a potentiometer-voltmeter with a high-resistance calibrated galvanometer a vacuum-tube voltmeter which is fully battery operated with ranges from 100 millivolts to 10 volts with 500,000 ohms input resistance; a milliammeter and ammeter with full scale ranges of 1 milliampere to 20 amperes; and a zero-resistance type ammeter with capacity up to 2 amperes. A d-c biasing potential is provided to "backto-zero" a galvanic potential - to provide for measuring a change in potential directly on the calibrated galvanometer, high-resistance volt-

meter or the vacuum-tube voltmeter. Polarity reversing switches are included for each instrument. Arrangements are provided for measuring the resistance of shunts, leads, resistors, etc.; also for measuring soil resistivity either by the four-electrode method or of soil samples in a soilbox—covering a very wide range of resistivity with unusually high accuracy. Full details can be secured from the manufacturer, M. C. Miller, 1142 Emerson Avenue, W. Englewood, N. J.

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A packless valve, No. 3000 Series, said to be suitable for numerous applications, has been developed by Fulton Sylphon Div., Dept. P-V, Robershaw-Fulton Controls Co., Knoxville, Tenn. Leakproof performance and freedom from maintenanc are said to be provided by the seamless metal bellows used between the valve disc and the valve body. A new feature of these valves is that they are available equipped with stainless steel bellows and stainless steel bodies, making them suitable for use where corrosive and other metal wearing actions are encountered. The bodies of the valves are also available in bronze, cast iron, cast steel, or Monel. The bellows is available in either stainless

steel, Monel, phosphor bronze, or brass. For high vacuum service, a composition disc is used in lieu of a metal disc. According to the manufacturer, the valves are applicable to temperature services up to 300° F. in the screwed end type. For temperatures from 300 to 700° F. a yoke and external thread construction is used, and by special construction, they may be made suitable for temperatures up to 1200° F. They are made in sizes from ¼ to 3 inches with screwed, welded, or flanged ends.

Literature describing the salient features of the Wilkinson Line Locator is available upon request from the Wilkinson Products Company, P.O. Box 1774 Wilshire-LaBrea Station, Los Angeles 36, Calif. The new locator, light in weight, and compact, is effectively operated by one man. It is one-third as bulky and one-half as heavy as previous inductive type locating devices, and is claimed to be more stable and less liable to maladjustment, and to function satisfactorily under conditions which hamper locating work with old designs. The circuit is of the high gain type, powered by common flashlight batteries.

A new Oasis Electric Drinking Water Cooler designed for maximum protection against rust from condensation of high-humidity air, corrosion from fumes, and mechanical damage from lint and dust is being introduced by the Ebco Manufacturing Co., 401 W. Town St., Columbus. Known as the Model OP-10W Oasis, the new pressure type cooler prevents damage from rust, corrosion, and dust and lint

by having its water-cooled condensing unit and other vital mechanical parts sealed in an air-tight pressurized cabinet especially designed and insulated for complete protection.

A new folder, die cut in the distinctive shape of their recently-introduced Flat Top anode, has been released by Wagner Brothers, Inc., of Detroit, Mich. The two-color four page folder describes advantages of the new zinc anode, principally the shape which eliminates possible confusion of zinc with cadmium or tin anodes. Copies are available by writing Wagner Brothers, Inc., Dept. K, 438 Midland Ave., Detroit 3, Mich.

A 36-page handbook containing data on stainless steel has been prepared by the Alloy Metal Wire Co., Inc., Prospect Park, Pa. Many new innovations have been made for comparing qualities, characteristics, uses, mechanical, physical, electrical, magnetic, heat resisting and corrosion resistant properties of stainless steels. Extensive technical data has been compiled in graphs, charts and tables.

A new control valve, "Microflo," with spline plug designed to handle small flows measured in cubic centimeters with pressure drops in thousands of pounds, has been announced by Hammel-Dahl Co., 243 Richmond St., Providence, R. I. Basic element of the valve is a solid stellite valve plug which is a honed fit in a solid stellite seat. Clearances between the plug and seat cannot be measured by ordinary methods, yet galling does not occur because of the type of metal used, according to the manufacturer.

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Corrosion Abstracts

CHEMICAL CORROSION

Scaling at High Temperatures in Sulfur Dioxide. Oxygen and Nitrogen-Containing Atmospheres. J. H. Nicholson & E. J. Kwasney, Consolidated Mining & Smelting Co. Paper before 91st Gen. Mtg., Electrochem. Soc. April 9-12, 1947, Louisville, Ky. Electrochem. Soc. Preprint 91-28, 419-429 (1947).

Data on corrosion of steel, alloy steels, cast iron and calorized steel in sulfur dioxide-oxygen-nitrogen atmospheres at elevated temperatures. Increase in temperatures have a more serious effect on corrosion rates than have increases in sulfur dioxide or oxygen concentrations. Calorized steel and "AISI Type 316 columbium" (17.9% nickel — 12.6% chromium - 2.05% molybdenum -0.6% columbium — 0.55% silicon) appear to be promising materials of construction for equipment operating in sulfur dioxide atmospheres at high temperatures, but the cost of the latter may limit its use in practice.-INCO.

Absorption of Hydrogen by Aluminum in Caustic Soda Solution. C. E. RANSLEY & H. NEUFELD, Nature (England) 159, No. 4047, 709-710, (1947) May.

In some experiments reported recently by Moreau and Chaudron, it

AMC

was found that prolonged immersion of high-purity aluminum in dilute 0.01 normal caustic soda solution resulted in absorption of large quantities of hydrogen by the metal, and that presence of this gas had a measurable effect upon the elastic modulus. Research Laboratories of the British Aluminum Company, Ltd., carried out some tests in which the corrosive conditions were identical with those described by Moreau and Chaudron; but the hydrogen absorbed by specimens was determined by a hot-extraction method. In these tests, two specimens of cast 99.99% aluminum, each weighing about 10 g., were immersed in 0.01 normal caustic soda for 49 days, the solution being renewed at frequent intervals when the reaction appeared to be slowing down. Specimens each lost about half a gram in weight and were very deeply etched, especially at the grain boundaries. On removal from the solution, they were washed in 1% acetic acid and dried without handling. One specimen was degassed without any further treatment, and evolved hydrogen equivalent to 0.47 cc/100 g. of metal, and a much smaller volume of other gases, mainly carbon dioxide. The second specimen was skimmed to a depth of about 1 mm. on a lathe before degassing, and in

this case the hydrogen content was found to be 0.43 cc/100 g., with a lesser volume of other gases than in the first experiment. Other experiments indicated that with the latter treatment the bulk of the gases other than hydrogen, and about 0.05 cc/100 g. of the hydrogen itself, is associated with the oxide film which is inevitably present on the metal. The correction to obtain the true value of dissolved hydrogen is probably greater than this for the unturned specimen. Thus, the hydrogen content of the corroded metal was rather less than 0.4 cc/100 g. with no evidence of a high concentration in the surface layers. A gas content of this order is quite normal for cast aluminum and, therefore, it is concluded that no appreciable absorption of hydrogen takes place. It has been impossible to detect any effect of the magnitude described by Moreau and Chaudron.-ALL.

Safe Disposal of Waste Solutions from Electroplating Shops. H. KRAUSS. Fertigungstechnik, 2, No. 7, 175-177 (1944).

Detailed description of various practical methods of treating and detoxicating pickle liquor (killing, settling basins, requisite dilution and recovery of copper), spent chromium plating baths (toxicity of chromic acid and its salts, and best method of rendering such baths harmless on basis of titrimetric determination of chromate content), and potassium cyanide baths (hazards to be avoided, conversion of cyanide to Prussian blue, areation in basins, and addition of oxidizing agents).—INCO.

Reactions of Magnesium and Aluminum with Iodine and With Concentrated Sulfuric Acid. Leon McColloch. J. Chem. Education, 24, 240 (1947) May.

Experiments show that magnesium forms a passivating film in iodine which protects it even up to 600° C., while aluminum reacts readily. In cold 98% sulfuric acid films are formed on both metals, but the one on aluminum gives only partial protection.—BLR.

COATINGS

German Acetylene Chemical Industry-Corrosion-Resistant Linings, BIOS Report 1058; 39 pp.

Account of the various lining materials tried for apparatus used in various stages of this industry. The materials discussed in connection with linings are Buna; Igelit: Oppanol; Phenytal; Atephen; Dional, and a 65-70% iron ferro-silicon, which proved to have properties varying considerably from those of the conventional 15% silicon ferrosilicons. Details are given of methods used for soldering this material to form linings for chemical plant. Thermal conductivity and other properties of the lined vessels are discussed.—INCO

Contribution to the Knowledge of the Corrosion Protection of Duralumin Alloys by Cladding. H. J. See MAN & M. DUDEK. Korrosion u. Metallschutz, 19, No. 6, 165-169 (1943); J. Inst. of Metals & Metall. Abs., 14, 107 (1947) March.

Duralumin alloys were clad on one side with an aluminum alloy containing magnesium 0.8-0.9% and magnen in ioup to reacts ic acid als, but

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silicon 1%, and on the other side with various grades of pure aluminum. After solution treatment at various temperature and times, followed by cold and warm ageing, corrosion tests were carried out by alternating immersion in a 3% solution of sodium chloride. Corrosion results were correlated with microscopic examination of diffusion of copper into the cladding material, as revealed by etching for 180-240 sec. in a mixture of hydrofluoric, hydrochloric, and nitric acids. The results showed that: 1) so long as the aluminum-silicon-magnesium cladding alloy contains < 0.3% copper, the corrosion properties are not appreciably affected by the ageing treatment and there is little intercrystalling corrosion; and 2) cladding with pure aluminum leads to diffusion of copper from the basis metal into the coating and to coarse crystal formation during the solution treatment, rendering the coating susceptible to breakdown of the surface layer, micro-pitting, and severe intercrystalline corrosion .-INCO

Anodizing of Magnesium Alloys for Protection and Appearance. George Black. Prod. Eng. 18, 122-124 (1947) May.

Electrolytic process forms protective and decorative magnesium-oxide-silicate film on alloys of magnesium. Selection of ac or dc process and the effect of film on corrosion, mechanical properties, dielectric strength, and alkalinity are among the significant factors explained and discussed.—BLR

Surface Corrosion Protection of Magnesium by Means of Chemical Reactions and by Coating with Protective Materials. (In German.) HELLMUTH WEIS. Mitteilungen des Chemischen Forschungsinstitutes der Industrie Osterreichs, 1, 42-44 (1947) Feb.

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Compares the resistance to corrosion of a magnesium surface after chemical or electrolytic treatment with that of one coated with protective substances such as paints, varnishes, resins, etc.—BLR.

Three Scuff-Resistant Coatings for Ferrous Wearing Surfaces. Based on Paper, Scuff and Wear Resistant Chemical Coatings. By F. C. Young & B. B. Davis. SAE Journal, 55, 42-43 (1947) May.

Discusses some specific applications of manganese iron phosphate coating, iron oxide coating, and caustic sulfur coating.—BLR

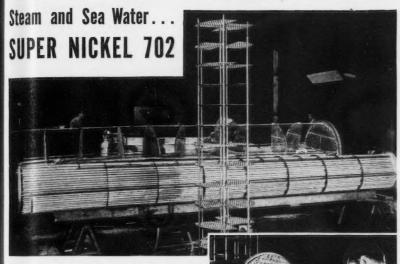
Surface Preparation and Film Thickness. Henry L. Bottemiller. Paint, Oil & Chem. Rev. 110, 14-15, (1947) May 15.

Describes results of a Navy pointtesting program in which application techniques, as well as different paints, were evaluated. Results indicate that the poor service given by most ship paint jobs during the war was caused by improper application techniques and lack of sufficient number of coats. Four coats were found to be superior to two.—BLR

Application of Metallic Coatings. RICK MANSELL. Metal Fin. 45, 62-65 (1947) May.

Survey of corrosion, cleaning and pickling, polishing methods, and

For LONG-LIFE in contact with Petroleum, Tar, Gas Vapors,



Photos show the retubing of No. 2 Fuel Oil Cooler, bundle 332, for Combination Unit No. 7 at the Bayonne, N. J. Refinery of Tide Water Associated Oil Company.

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THIS ALLOY, 70-30 copper-nickel to A.S.T.M. B111-47, is being used increasingly under highly corrosive conditions in the refining field.

Large quantities of Super Nickel 702 are being used by the Tide Water Associated Oil Company in its Bayonne, N. J. Refinery. Considerable retubing of heat exchangers cooled by salt water was undertaken during 1947, and the work continues.

Here, it was necessary to find a tube material that would resist not only the destructive forces commonly encountered in petroleum cracking and refining but withstand as well the action of a corrosive coolant, salt water from Bayonne harbor.

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Subsidiary of Anaconda Copper Mining Company General Offices: Waterbury 88, Connecticut In Canada: ANACONDA AMERICAN BRASS LTD., New Toronto, Ont. electrodeposition processes in metallic coatings. (To be concluded).—BLR

Protective Coatings Under Test. Chem. Engr. 54, 154-155 (1947) May.

Outlines cooperative test program of Sherwin-Williams and Dow Chemical being conducted at the latter's Freeport, Texas, plant. Test panels are exposed to air laden with both marine salts and miscellaneous chemical fumes.—BLR

New Anticorrosive Finish Gives 20 Years' Protection. Iron Age, 159, 76, 152 (1947) May 22.

Describes new coating developed to protect ferrous metal surfaces from atmospheric corrosion. It is claimed to afford protection to metals exposed to severe weathering conditions, for a period of 20 years or more without further application. It can be applied cold by brushing, spraying, or dipping; sets up in a short time and can be pigmented, painted, or plated. Describes results of exposure testing.—BLR

Organic Finishes for Increasing the Life of Bus and Truck Parts. Roy B. Davis. Soc. of Auto. Engrs. New York. Preprint, 17 pp. (1947).

Considers nature of metal to be finished, conditions of exposure, and painting. Metals concerned are steel and aluminum alloys, with brief reference to zinc die castings, zinc plated sheets, and magnesium alloys. See also: No. 76 (cathodic pickling), No. 125 (corrosion-preventive coatings), No. 198 (testing pickling inhibitors), No. 282 (electropolishing in metallography), No. 582 (paint

for aluminum ships), No. 728 (coloring power of pigments), No. 96 (corrosion resistant surface treatment for zinc).—BLR

Use of Glycerine in Metal Protection. G. Leffingwell & M. A. Lesser. Corros. and Mat. Prot. (U.S.A.) 4, No. 3, 12, 22-23, (1947) May-June.

Value of glycerine in metal protecting processes and materials mar be divided into two main parts: 1) those employing glycerine itself, 2 those using alkyd resins made with glycerine. Glycerine has a role in the anodic treatment of aluminum. The hard oxide coatings formed by such treatments are among the most durable of protective finishes. Not only do these coatings provide an attractive appearance, high corrosion resistance, high dielectric strength and high reflectivity, but they also form a good base for subsequent coloring with dves or pigments. Employed in varying proportions in the electrolyte bath, glycerine usually acts as an inhibiting agent to prevent undue etching of the metal and thus helps the formation of a finer, whiter and smoother surface. It may be used in baths containing sulfurio acid, such as the now standard Alumilite, Tennents and Anotint proc esses, as well as more recently devel oped methods using this acid. It such baths, glycerine has been found to decrease the solubility of the aluminum and to aid in the formation of a more plastic film. It is also em ployed in anodizing baths contain ing chromic acid, organic acids, or sodium hydroxide. In the prepara tion of non-metallic protective coal ings for metal, such as lacquers glycerine may serve as a plasticizing

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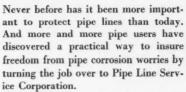
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Plants at: Glenwillard, Penna.; Longview, Texas; Corpus Christi, Texas; Harvey, La.; Sparrows Point, Md. agent to counteract brittleness, cracking, and chipping. Many liquid anti-rust compositions which may be brushed, sprayed, or otherwise applied to metal surfaces use glycerine.

—ALL.

Chemically Generated Film Aids in Corrosion Control. Steel, 120, 101-102 (1947) June 2.

Describes latest developments on a method that converts the surface of zinc or cadmium into a complex chromate.—BLR

FUNDAMENTALS

Fundamental Factors in Corrosion Control. H. H. Uhlig. Corrosion, 3, 173-184 (1947) April.

Cathodic protection, metallic coatings; galvanic behavior; inhibitors and passivators; corrosion-product coatings; alteration of environment; metal purification are discussed.—BNF

Electron Shifts and Corrosion. K. Wickert. Korrosion u. Metallschutz, 19, No. 5, 125-130 (1943) J. Inst. of Metals & Metall. Abs. 14, 104-105 (1947) March.

General principals underlying the electron-transfer theory of corrosion and theory of galvanic chains are discussed. Expressions are derived for correlating the solution pressure of a metal with its electron activity, and it is shown that the electron-production potential is equal to the ion-production potential. The various types of corrosion can be divided into three classes: 1) electronic corrosion, in which a transfer of electrons takes place, e.g., the destruction of a metal: 2) atomic corrosion.

in which neutral atoms react with one another, e.g., the reaction between iron and carbon monoxide to form carbonyls; 3) ionic corrosion, in which there is an exchange of ions. The theory is further discussed with reference to the rusting of iron and steel under various conditions, the formation of copper-ammonia complexes, and the behavior of materials containing the oxides of aluminum, boron, chromium, and silicon. Bronsted's acid-base theory and Lewis's definition of a base are reviewed.—INCO

GENERAL CORROSION

Economic Aspects of Corrosion Problems. F. A. ROHRMAN, Kansas State College. Corrosion, 3, No. 2, 67-72 (1947) Feb.

Brief reviews of factors involved in corrosion costs, equipment and plant replacement, maintenance costs, loss of products, power losses, contamination and discoloration, corrosion research. While general in scope, each point is illustrated by concrete, illuminating cases or statistics.—INCO

Rust, Industry's Arch Enemy. T. TRAIL. Power Plant Engr. 51, No. 6, 84-86 (1947) June.

Theory of rust, requirements of preservative coatings, use of colors to provide contrast between coats of protective coatings, preparation of surfaces preliminary to applying protective coatings, special treatment for galvanized iron and paints for various surfaces are discussed.

—INCO

Corrosion. M. G. FONTANA. Ind. & Engr. Chem. **39**, No. 4, 81A-82A (1947) April.

Right: Gas line, coated with Reilly Enamel.

Right: Gas line, coated with Reilly Enamel.

Left: Water lines, coated and lined with Reilly Enamel.

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Reilly Pipe Enamel gives dependable, lasting protection against corrosion to oil, gas and water lines. As an outside coating, Reilly Enamel completely seals and insulates the metal against its environment, thus preventing all corrosive agencies from coming in contact with the metal. As a lining for water lines, Reilly Enamel not only protects against corrosion, but also prevents incrustation and tuberculation, thus insuring full-flow capacity for the life of the pipe.

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The eight forms of corrosion are defined as: uniform attack or general corrosion, intergranular corrosion, galvanic or two-metal corrosion, erosion-corrosion, dezincification, pitting, stress-corrosion, and concentration cell corrosion. Intergranular corrosion is discussed with examples, including 18-8 stainless. Intergranular attack on high alloy stainless castings. Weld decay zone and stabilization with titanium for 18-8 weld is shown. Intergranular corrosion of nickel shrouding after several years of service in a high temperature steam turbine in a chemical plant is also shown and discussed. Its successful application for this use is, however, mentioned. -INCO

Corrosion Processes (Concluded). U. R. Evans. Metal Ind. 70, 355-357 (1947) May 16. Concludes review of British work. 40 refs.

The Film Theory of the Passivity of Metals—Parts I and II. V. Cupr. Korrosion u. Metallschutz, 19, No. 5, 130-140 (1943); Ibid, 20, No. 2, 98-107 (1944); J. Inst. of Metals & Metall. Abs., 14, 119 (1947) March.

Muller's film theory of passivity and the objections of Weiner and Halla are critically reviewed from a mathematical viewpoint. The thickness and area of the film, the rate of passivation, the current strength at the beginning of passivation, and the values of Mueller's integration constants are discussed. Although modifications of his formulae are advanced, they are purely mathematical in character and have no effect on the practical values obtained. The

results of Weiner and Halla as to the influence of the film on the electrode potential are shown to be based on an incorrect use of Kirchoff's laws; their objections to Mueller's theory are unsupported.— INCO

Corrosion Costs—Readers Report. H. H. Anderson, Shell Pipe Line Co., Business Week, No. 925, 37-38 (1947) May 24.

Letter to editors differs with corrosion figure from Business Week, April 19, 1947, of \$6 billion annual corrosion loss. Claims depreciation allowed by ICC on American pipelines indicates annual replacement of \$200 million, a fair statement of corrosion losses. An estimate of \$300 million due to corrosion in other industries (source not given), brings total to \$500 million per year.—INCO.

INHIBITORS

Inhibiting Action of Sodium Chromate and Potassium Permanganate on Attack on Aluminum by a Dilute Solution of Sodium Hydroxide, at Various Temperatures (In Italian). Nello Collari. Alluminio, 15, 13-21 (1947) Jan.-Feb.

Sodium chromate and potassium permanganate inhibit attack on 99.5 aluminum immersed in a 0.5-1% solution of sodium hydroxide at 2-50° C. by forming protective oxide layers on the aluminum. The degree of effectiveness varies with the temperature. In general, potassium permanganate is the more effective agent.—BLR

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temm perfective New Corrosion Inhibitor (Elset). Oil & Gas J. **46**, No. 1, 105 (1947) May 10.

Functions by building a protective film of molecular thickness on well equipment surfaces that are exposed to destructive fluids. The chemical is dispersed in water, then introduced into casing through a lubricator. Continuous injection is reported unnecessary, but rather about 2 qt. every other day has proved satisfactory.—INCO

The Use of Dehydration in Combating Internal Corrosion in Products Pipe Line Systems. HARRY K. PHIPPS. Proceedings Am. Petro. Inst. 26, Section V, 37-40 (1946); Corrosion 3, 458-465 (1947) Sept.

After a rather lengthy period of investigation, it was found that line capacities could be maintained by employing a regular schedule of interior scraping; by introducing anticorrosion inhibitors; and by dehydration of the product prior to delivery to the pipeline. Primarily concerned with the latter technique.—BLR

INSPECTION

Equilateral Electric Strain Gauge Rosette. G. Brewer, Metal Prog. (U.S.A.) 51, No. 5, 758-763, (1947) May.

The equilateral strain gauge rosette is a device wherein three small electric strain gauges are cemented to the area under study, so arranged that their axes correspond to the sides of an equilateral triangle. After such a rosette is cemented to the surface to be studied and wired to proper instruments, the structure is loaded as desired and the resulting

strains recorded for each of the gauges. Simultaneous readings along the three legs of a single rosette will give all the information.

Evaluating Pickling Acid Inhibitors. E. L. Colichman, R. C. Thielke and B. J. Cotey, Turco Products, Inc., Iron Age, 159, No. 17, 55+ (1947) April 24.

Describes an easily performed colorimetric test method for determining the extent to which a steel surface has been atacked by pickling acid solutions. Procedure is described.—INCO.

PIPE CORROSION

Corrosion Coupons and Pipe Life Predictions—Revision of 1947. W. R. Schneider, Pacific Gas & Electric Co., Corrosion, 3, 209-20 (1947).

Pipeline corrosion rate measurement and pipe life prediction by the buried coupon technique are comprehensively described. The coupons, 3" x 6" x 5/16" cleaned steel plates. are buried in pairs near the bottom of the pipe. One of the coupons is electrically connected to the pipe and is acted on by stray and long line currents as well as by the soil; the other coupon is a control subject to soil action only. The coupons are removed yearly, preferably in the fall, and corrosion, particularly pit depth, measured. The mathematics of accurately estimating cumulative pit depth from yearly measurements of individual pits are given in full detail. The method can be successfully applied to old lines in the absence of previous data. Some remarkable instances of accurate pipe life predictions, detection of corrosion conditions, and detection of changes

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rosion anges Recognizing the time-saving, cost-saving value of instant, dependable communications, The El Paso Natural Gas Co., chose Motorola Radiotelephone to expedite the construction of 1115 miles of pipe line between the Panhandle and California. That this progressive company chose wisely is proved by the fact that the installation paid for itself in one month of operation.

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in soil corrosivity from various causes are cited.

SURFACE TREATMENT

Parkerizing: Growth or Shrinkage? N. A. Tope, Am. Electroplaters' Soc., Proceedings 33rd Annual Convention, 293-304 (1946) June.

Author's experience on the effect of a Parker "A" phosphate treatment on the dimensions of 1/4" hightensile steel studs.—BNF.

Electroplating and Cathodic Pickling as Causes of Hydrogen Embrittlement. CARL A. ZAPFFE AND M. ELEANOR HASLEM, Wire & Wire Products, 22, 351-356, 379-381 (1947) May.

Describes a new bend test said to be especially suitable for measuring brittleness of wire specimens. Demonstrates the effects of pickling time, bath temperature, and bath impurities on hydrogen embrittlement during cathodic pickling. Shows that hydrogen absorption is identical for acid or for alkaline electrolytes. Gives a quantitative evaluation of embrittlement caused by chromium plating and by cadmium plating. Both the latter are shown to cause embrittlement equaling or exceeding that caused by cathodic pickling—BLR.

Metal Cleaning—Methods and Results. J. R. Ewing. Solventol Chem. Products, Inc. Steel, 120, No. 18, 104, 101, 1 (1947) May 5.

Types of cleaning materials at classified and their use described with special emphasis on multiple phase type cleaners, recently developed. This cleaner brings together in



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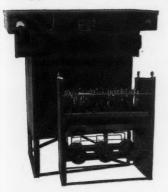
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Corrosion Protection of the Elektron Casting Alloy A9V by Surface Treatment. G. Elssner & H. Hunlich. Korrosion u. Metallschutz, 19, No. 6, 169-174 (1943); J. Inst. of Metals & Metall. Abs., 14, 108 (1947) March.

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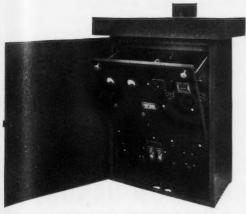


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Metal Preparation for Porcelain Enameling with a New Type Spray-Cleaning and Pickling Machine. G. TUTTLE, Benjamin Electric Mfg. Co., Finish, 4, No. 4, 19-22, 56 (1947) April.

The pressure spray continuous pickling machine represents the most recent development in prepar-

ing metal surfaces for enameling The automatic spray pickling machine now in use at the Benjamin Electric Manufacturing Co. is described.—INCO

TESTING

Use of the Spectroscope in the Determination of the Constituents of Boiler Scale and Related Compounds. A. Gabriel, H. W. Jaffe, & M. J. Peterson, Bureau of Mines ASTM Preprint No. 116, 6 pp (1947).

Use of the simple bunsen spectroscope as a replacement for qualitative chemical tests in determining the metallic (cationic) constituents of boiler scales and related compounds is discussed. The setup of the instrument and its operation are described, 6 ref.—INCO

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Evaluation of Metals for Process Equipment. A. Wachter and R. S. Treseder, Chem. Eng. Prog. 43, No. 6, 315-326 (1947).

The use of laboratory corrosion tests to determine the serviceability of metals for chemical process equipment is discussed. Factors to be considered in planning, conducting and interpreting tests are outlined. Details of experimental methods and a criterion for evaluating corrosion test results are presented.—CALCO.

Investigation of Oxidation of Copper by Use of Radioactive Copper Tracer. J. BARDEEN, W. H. BRATTAIN AND W. SHOCKLEY, J. Chem. Phys. 14, No. 12, 714-721 (1946) Dec.

A very thin layer of radioactive copper was electrolytically deposited on a copper blank. The surface was then oxidized in air at 1000° C. for 18 minutes, giving an oxide layer with a thickness of 0.0125 cm. After quenching, successive layers of the oxide were removed chemically, and the copper activity in each layer was measured. The results give a fairly direct confirmation of the theory of oxidation first suggested by Wagner.—BNF.

Methods of Determining Resistance of Nickel and Nickel Alloys to Corrosion (Hydrochloric Acid). F. L. LaQue, Canad. Met & Met. Ind. Nov., 1946, 9 (11), 28-32.

Nickel and high-nickel alloys have good resistance to attack by hydrochloric acid solutions. This article describes methods and results of testing these materials having regard to the following factors: cost



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Long-Term Natural Corrosion Tests on Different Structural Steels in the Atmosphere and in Sea and River Waters. Report I, H. BAUDOT; Report II, G. CHAUDRON, Rev. Met., Jan-Feb., 1946, 43 (1/2), 1-67.

First two reports on a comprehensive series of tests covering a wide range of structural steels (unprotected) exposed at 11 different stations since 1938. (1) describes preparation of specimens and test stands; (2) gives an analysis of the results and a comparison with laboratory tests.—BNF.

Half Cell for Measuring Corrosion Potentials. J. M. STANDRING, Am. Tel. & Tel. Co. Elec. World, 127, No. 3, 182+ (1947) Jan. 18.

A home-made half cell, for measuring potential on underground structures to ground, using telephone receiver shell for housing, wood plug for earth contact, is described and illustrated.—INCO

Corrosion-Research Balance Weighs Single Layer of Atoms. E. A. GULBRANSEN, Westinghouse Research Lab. Instruments, 20, No. 2, 106-108 (1947) Feb.

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of ten billionths of an ounce. The instrument is described and illustrated.—INCO

Measurement of Corrosion Pits in Boiler Tubes. B. M. THORNTON. Engr. 163, 229-230 (1947) Mar. 28.

Describes a tool designed to detect and measure corrosion pits using an electrical instrument previously described for measuring the thickness of boiler tubes in place, and of non-ferrous castings. A new exploring head was designed by means of which the location and presence of serious pitting is detected. One man moves the head steadily through the tube, while another watches the microammeter.—BLR

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Corrosion of Nickel-Aluminum Bronze Variable Pitch Propellers with Particular Reference to Target Control Boat C/T 101. Admiralty Corrosion Com., Hull & Non-Ferrous Corrosion Sub-Com. ACC/H 125/46, Metall. Report DAG, Serious and rapid corrosion of nickel aluminum bronze propellers in sea water has occurred with material not complying with DTD 412, the manganese content being too high and the nickel too low. Example is described. There is some doubt whether DTD 412 may be too wide a specification for nickel-aluminum bronze for seawater service. Experimental work is necessary to permit a decision to be reached.-INCO

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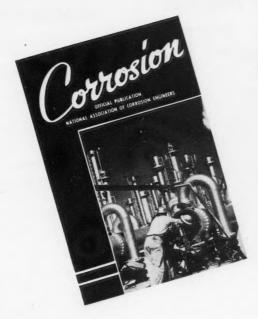
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American Hot Dip Galvanizers Association 42
Aluminum Company of America (Alcoa)19
Bechtel Corporation & H. C. Price Company. 43
Cathodic Servicing Company
Dearborn Chemical Company. Inside Front Cover
Dixie Tank & Bridge Company30
Dow Chemical Company, The
Electro Rust-Proofing Corporation
General Paint, Hill-Hubbell Co., Division Inside Back Cover
Haering, D. W. & Company, Inc
Jacobs Wind Electric Company, Inc., The35
Johns-Manvilleviii
Koppers Co., Inc
Mavor, James E32
Mayes Brothers, Inc.
Midwestern Engine & Equipment Co., Inc vi
Motorola, Inc
National Carbon Company, Inc
Nelson Electric Manufacturing Co33
Owens-Corning Fiberglas Corporationvii
Perrault Brothers, Inc
Pipe Line Service Corporation
Reilly Tar & Chemical Corporation
Service Engineers, Inc., & Plastelite Engineering Co
Stearns, D. EOutside Back Cover
Wiley, John & Sons, Inc34
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.30

.38

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.39

.35

. Viii

.37

.32

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.29

.44

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. . 27

Cover

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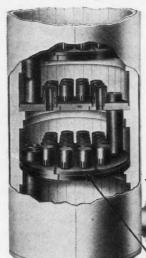
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